

# UNDERSTANDING ULTRASOUND PHYSICS

FOURTH EDITION

SIDNEY K. EDELMAN, PH.D.









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# **UNDERSTANDING ULTRASOUND PHYSICS**



**FOURTH EDITION**

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To my sister Ruth,

With gratitude and love,

SKE



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## PREFACE

To keep abreast of the ever-changing requirements for registry credentials, it is time to publish the 4th edition of *Understanding Ultrasound Physics*. New processes in the publishing industry allow us to publish smaller quantities so that now we can quickly inform readers of the latest topics and technologies. We continue to innovate in the arena of physics exam preparation.

In this 4th edition, we have added chapters describing optimization of Doppler imaging and sonographers in the clinical setting. We have added many topics such as patient communication, medical ethics, informed consent, ergonomics, elastography, and standard precautions that should be taken as part of the educational and exam preparation processes. We have expanded the information provided on quality assurance, bioeffects, displays, and imaging processing, and restructured much of how we present basic physics information, including axial and lateral resolution.

As in the past, our attention to detail, illustrations, and content continue to serve as a foundation for the sonographer. The text provides numerous examples, questions, and quizzes. We have continued to refine our educational model to enhance the learning process.

Although the text contains many equations, solving numerical examples is not a required skill for most ultrasound board exams. Devote your energy instead to understanding concepts and relationships. Incorporate the same skills to the study of physics that you use each day as a clinician. It is our hope that presenting the material in alternative formats will allow each of us to *Understand Ultrasound Physics*. Review the material carefully, but keep in mind that memorization without understanding is less than what we should expect of ourselves.

I hope that this text enhances the quality of and satisfaction in your chosen career. Carry joy throughout your day.

SKE, Woodlands, Texas





## ACKNOWLEDGMENT

Learning occupies every moment of our lives. Some of the time, we are aware of it. Often times, it is our invisible partner. Looking in the past, we see that learning is our constant companion.

I have learned the privilege of sharing life with exceptional individuals. It is impossible to do justice in recognizing four extraordinary friends and colleagues, David Adams, RDCS, RCS; Steven Bernhardt, BS, RDMS, RVT; Micky McPharlin, RN, RVT; RVS; and Claudia Rumwell, RN, RVT. I hope that our journey has provided you with unbounded goodness.

My travels have taken me throughout the nation and I have learned that I am the son of the smartest woman in America, Mildred Edelman.

I have learned that expertise is priceless. Many thanks to Melanie G. Flanders and Brian D. Carr for their essential contribution in the preparation of this text.

Finally, to those who, over the years, have expressed kind and caring words of appreciation—you have stimulated my mind and my heart, and have taught me so much. Thank you.

*Sidney K. Edelman Ph.D.*



# Contents

## Chapter

### 1 The Basics 1

### 2 Sound 11

Sound Waves 11  
Acoustic Variables 12  
Acoustic Parameters 12  
In-Phase and Out-of-Phase Waves 14  
Review: Sound 16

### 3 Describing Sound Waves 19

Period 20  
Frequency 21  
Three “Bigness” Parameters 27  
Wavelength 33  
Propagation Speed 36  
Review: Describing Sound Waves 41

### 4 Describing Pulsed Waves 47

Pulse Duration 49  
Spatial Pulse Length 51  
Pulse Repetition Period 53  
Pulse Repetition Frequency 56  
Duty Factor 60  
Parameters That Describe Both Pulsed and Continuous Waves 64  
Review: Pulsed Waves 65

### 5 Intensities 69

Measuring and Reporting Sound Beam Intensity 70  
Spatial Considerations 70  
Temporal Considerations 71  
Combining Spatial and Temporal Factors 72  
The “Ten Commandments” of Intensity 74

## Chapter

### 6 Interaction of Sound and Media 75

Decibels (dB) 77  
Attenuation 80  
Attenuation Coefficient 84  
Reflection and Transmission 88  
Impedance 88  
Summary: Reflection, Transmission, and Refraction 104  
Review: Attenuation & Reflection 106

### 7 Range Equation 107

Time-of-Flight or Go-Return Time 107  
Review: Range Equation 111

### 8 Transducers 113

Basic Transducer Construction 114  
Transducer Frequencies 122  
Review: Transducers 126

### 9 Sound Beams 129

Shape of a Sound Beam 130  
Anatomy of a Sound Beam 130  
Determining Focal Depth 135  
Sound Beam Divergence 139  
Spherical Waves 142  
Huygens’ Principle 142  
Review: Sound Beams 143

### 10 Axial and Lateral Resolution 145

Axial Resolution 145  
Lateral Resolution 151  
Focusing 154

## Chapter

## Chapter

### 11 Display Modes 159

1. A-mode—Amplitude 159
2. B-mode—Brightness 161
3. M-mode—Motion 162

### 12 Two-Dimensional Imaging 165

- Mechanical Transducer 167
- Linear Phased Arrays 169
- Annular Phased Arrays 178
- Linear Sequential Arrays 180
- Vector Arrays 186
- Slice Thickness or Elevational Resolution 188

### 13 Real-Time Imaging 197

- Temporal Resolution 198
- Imaging Depth 200
- Number of Pulses per Image 201

### 14 Pulsed Echo Instrumentation 215

- Pulser 217
- Beam Former 221
- Receiver 223
- Output Power vs. Receiver Gain 235
- Review: Pulsed Echo Instrumentation 236

### 15 Displays and Image Processing 239

- Display Controls 240
- Analog and Digital Image Data 247
- Magnification 250
- Coded Excitation 253
- Spatial Compounding 254
- Frequency Compounding 255

- Edge Enhancement 255
- Persistence 256
- Fill-in Interpolation 257
- Emerging Technology: Elastography 258
- PACS and DICOM 259
- Recording and Archiving Techniques 260
- Review: Displays and Image Processing 261

### 16 Dynamic Range 265

- Dynamic Range of System Components 266
- Number of Choices 268

### 17 Harmonics and Contrast Agents 269

- Fundamental and Harmonic Images 270
- Tissue Harmonics 272
- Pulse Inversion Harmonics 275
- Contrast Agents 278
- Contrast Harmonics 278

### 18 Hemodynamics 285

- Flow 286
- Laminar vs. Turbulent 287
- Energy Gradient 289
- Forms of Energy 289
- Energy Losses in the Circulation 290
- Stenosis 292
- Bernoulli's Principle 293
- Pressure-Flow Relationships 294
- Ohm's Law 294
- Venous Hemodynamics 295
- Hydrostatic Pressure 296
- Breathing and Venous Flow 300

## Chapter

### 19 Doppler 303

- Speed vs. Velocity 305
- The Doppler Equation 306
- Bidirectional Doppler 311
- Continuous Wave Doppler 312
- Pulsed Wave Doppler 314
- Aliasing 315
- Color Flow Doppler 325
- Doppler Artifacts 334
- Spectral Analysis 335

### 20 Optimizing Doppler Imaging 341

- Normal Incidence 342
- Color Doppler Gain 344
- Spectral Doppler Gain 346
- Aliasing 347
- Flow Reversal vs. Aliasing 348
- Wall Filter 351
- Wall Filter vs. Increasing Scale 354

### 21 Artifacts 355

- Image Characteristics 356
- Basic Assumptions of Imaging System 356
- Reverberation 357
- Comet Tail 358
- Shadow 359
- Enhancement 361
- Mirror Image 363
- Speed Error 364
- Lobes 366
- Refraction 368
- Slice Thickness 369
- Lateral Resolution 370
- Axial Resolution 370
- Review: Artifacts 376

## Chapter

### 22 Quality Assurance 379

- Requirements 380
- Objective vs. Subjective Standards 381
- Tissue Equivalent Phantom 382
- Doppler Phantom 383
- Slice Thickness Phantom 384
- Performance Measurements 385

### 23 Sonographers in the Clinical Setting 391

- Major Principles of Medical Ethics 391
- Informed Consent 393
- Patient–Sonographer Interaction 394
- Sonographer–Work Environment Interaction 394
- Standard Precautions 396

### 24 Bioeffects 401

- Converting Sound Energy into Heat 403
- Risk–Benefit Relationship 405
- Study Techniques 407
- Mechanisms of Bioeffects 408
- Epidemiology 413
- Clinical Safety and Prudent Use 414
- Electrical Safety 417

### Exam Review 423

### Index 553





# The Basics

## Graphs

In diagnostic ultrasound, information is often displayed in graphical form. For example, later in this text, we will see how the velocity of blood is reported on a graph.

The two axes (lines) used with all graphs (see Fig. 1.1) have special names:

- The **horizontal** axis, or **x-axis**, runs side to side.
- The **vertical** axis, or **y-axis**, runs up and down.

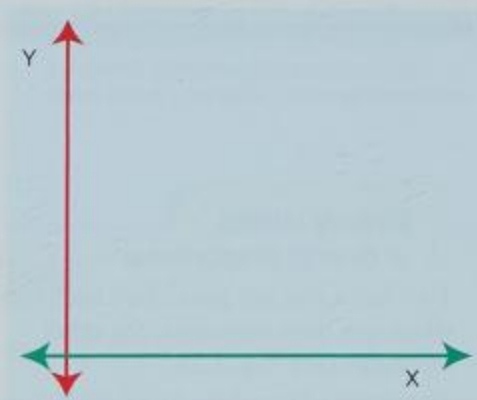


**Fig. 1.1** Standard labeling of a graph. The green horizontal line is called the x-axis. The red vertical line is called the y-axis.

## Definitions

The following terms are fundamental to understanding ultrasound physics:

### Unrelated

Two items that are not associated.

#### Examples

- Hair color is *unrelated* to shoe size.
- Weight is *unrelated* to day of birth.
- Temperature is *unrelated* to day of the week.

### Related, or proportional

Two items that are associated or affiliated. However, the relationship between the items does not have to be specified.

#### Examples

- Weight is *related* to dieting.
- Santa is *related* to Christmas.
- Exam score is *related to or proportional to* studying.
- Dental health is *related to* flossing.

### Directly related, or directly proportional

Two items that are associated such that when one item *increases*, the other *increases* (see Fig. 1.2).

The graph of two directly related items extends from lower left to upper right.

#### Examples

- Clothing size is *directly proportional* to one's weight.
- Age is *directly related* to experience.
- Skill is *directly proportional* to practice.
- Quality of wine is *directly related or directly proportional* to age.



**Fig. 1.2** Graph where two variables have a direct relationship. When the value of the x variable (age) increases, the value of the y variable (height) increases.

### Inversely related, or inversely proportional

Two items are associated such that when one item *increases*, the other *decreases* (see Fig. 1.3).

The graph of two inversely related items extends from upper left to lower right.

#### Examples

- Golf score is *inversely related* to skill.
- A car's gas mileage is *inversely proportional* to its engine size.
- Grades in school are *inversely proportional* to partying time.

### Reciprocal relationship

When two numbers with a reciprocal relationship are multiplied together, the result is one. This is a special form of inverse relationship. Reciprocal numbers are inverse because when one increases, the other decreases.

#### Examples

- 2 and  $\frac{1}{2}$  are *reciprocals*.
- 10 and  $\frac{1}{10}$  are *reciprocals*.
- Period and frequency are *reciprocals*. (Don't worry, this will be explained later in the text.)

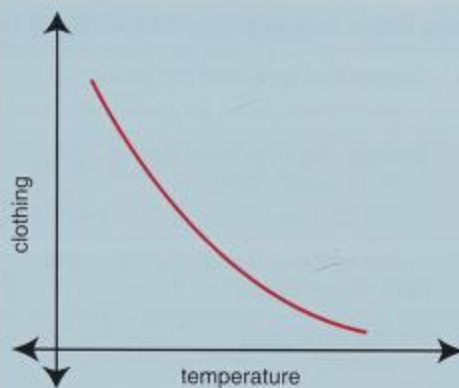
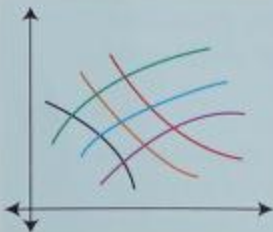


**Fig. 1.3** Graph where two variables have an inverse relationship. As the value of the x variable (temperature) increases, the value of the y variable (clothing) decreases.

| Questions                                                                           | Answers                                                                                                                         |
|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| <b>Are the following 8 pairs inversely related, directly related, or unrelated?</b> |                                                                                                                                 |
| 1. Cholesterol level and longevity.                                                 | 1. Inversely related. As cholesterol levels increase, life span generally decreases.                                            |
| 2. Smoking and the likelihood of cardiovascular disease.                            | 2. Directly related. Generally, individuals who smoke are more likely to have cardiovascular disease.                           |
| 3. Years employed and days of vacation earned per year.                             | 3. Directly related. Length of vacation time increases with length of employment.                                               |
| 4. IQ and shoe size.                                                                | 4. Unrelated. There is no relationship between shoe size and IQ.                                                                |
| 5. Caloric intake and weight.                                                       | 5. Directly related. Weight increases with the number of calories consumed.                                                     |
| 6. Hours spent exercising and weight.                                               | 6. Inversely related. Weight decreases with an increase in exercise.                                                            |
| 7. Alcohol intake and sobriety.                                                     | 7. Inversely related. Increased consumption of alcohol decreases sobriety.                                                      |
| 8. What is the reciprocal of 20?                                                    | 8. The reciprocal of 20 is $1/20$ .<br>$20 \times 1/20 = 1$ .                                                                   |
| 9. Which of the lines in the graph below represent an inverse relationship?         | 9. The red, orange and black lines represent an inverse relationship. These three lines extend from upper left to lower right.  |
|   |                                                                                                                                 |
| 10. Which of the lines in the above graph represent a direct relationship?          | 10. The green, blue, and purple lines represent a direct relationship. These three lines extend from lower left to upper right. |
| 11. Which lines in the graph represent relationships between two variables?         | 11. All of the lines represent relationships between the variables.                                                             |



## Units

All numerical values must have corresponding units. A number alone, without units, is ambiguous and can create uncertainty.

For example, the question “how old is Jenny?” calls for a numerical response with units. If the answer to this question is simply “6,” then it is incomplete. Is it 6 hours, 6 days, 6 years, or 6 decades?

In other words, for a numerical answer to a question to be comprehensive, it requires a **unit**.

- Units of **length**—distance or circumference: cm, feet
- Units of **area**:  $\text{cm}^2$ ,  $\text{ft}^2$
- Units of **volume**:  $\text{cm}^3$ ,  $\text{ft}^3$

**Notes:** Any fundamentally correct unit is acceptable. Although silly, a person can measure age in seconds!

“Increase by a factor” means to **multiply** by that number. Increase by a factor of 6 means six times larger.

“Decrease by a factor” means to **divide** by that number. Decrease by a factor of three means one third.

A number followed by the word “percent” is unitless.

## Unit Conversion

It is important to know how to convert from one unit to another.

These are forms of unit conversion:

- How many quarters are in 1 dollar?
- How many days are in 1 month?

**Note:** When units change, the “total picture” does not change; only the manner of presentation changes.

- Isn't 12 inches the same as 1 foot?
- Isn't 12 inches the same as  $\frac{1}{3}$  yard?

**Note:** Treat conversion units as fractions with a value of 1 and carry along the units.

### Examples

Convert

- \$5.00 into dimes  
(hint:  $\$1 = 10$  dimes)
- 12 inches into centimeters  
(hint:  $2.54 \text{ cm} = 1 \text{ inch}$ )



## Powers of Ten

Very large or very small numbers are difficult to write. **Scientific or engineering notation** is a shorthand manner to represent these types of numbers.

### Rules

A number in scientific notation form with a **positive** exponent has a value **greater than 10**.

A number in scientific notation form with a **negative** exponent has a value **less than 1**.

A number in scientific notation form with an **exponent of zero** has a value **between 1 and 10**.

To correctly calculate the number, perform these steps:

1. Shift the decimal point so the resulting number is between one and ten.
2. Multiply by the appropriate power of 10.

### Examples

- $1,000,000 = 1.0 \times 10^6$
- $0.000000124 = 1.24 \times 10^{-7}$
- $1742 = 1.742 \times 10^3$

## Metric System

Table 1.1 Metric System—Powers of Ten

| Exponent  | Prefix | Symbol | Meaning    |
|-----------|--------|--------|------------|
| $10^9$    | giga   | G      | billion    |
| $10^6$    | mega   | M      | million    |
| $10^3$    | kilo   | k      | thousand   |
| $10^2$    | hecto  | h      | hundred    |
| $10^1$    | deca   | da     | ten        |
| $10^{-1}$ | deci   | d      | tenth      |
| $10^{-2}$ | centi  | c      | hundredth  |
| $10^{-3}$ | milli  | m      | thousandth |
| $10^{-6}$ | micro  | $\mu$  | millionth  |
| $10^{-9}$ | nano   | n      | billionth  |

## Complementary Metric Units

Think of the pairs in Table 1.2 as belonging together. For example, if we speak of frequency in **megahertz**, then we will speak about period in **microseconds**; millions of cycles and millionths of seconds.

Table 1.2 Complementary Metric Units

| Pairs                     | Prefixes      | Abbreviations |
|---------------------------|---------------|---------------|
| billions and billionths   | giga & nano   | G & n         |
| millions and millionths   | mega & micro  | M & $\mu$     |
| thousands and thousandths | kilo & milli  | k & m         |
| hundreds and hundredths   | hecto & centi | h & c         |
| tens and tenths           | deca & deci   | da & d        |

## Review: The Basics

| Questions                                                                                                                                                                        | Answers                                                                                                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| 1. How are the size of a tree and its age related?<br>A. inversely<br><input checked="" type="radio"/> B. directly<br><input type="radio"/> C. unrelated                         | 1. B. directly. Generally, as a tree ages, its size increases.                                                            |
| 2. How are the height of a person and the color of his automobile related?<br>A. inversely<br><input checked="" type="radio"/> B. directly<br><input type="radio"/> C. unrelated | 2. C. unrelated. Generally, a person's age and car color have no relation to each other.                                  |
| 3. How is the age of a loaf of bread related to its freshness?<br><input checked="" type="radio"/> A. inversely<br>B. directly<br>C. unrelated                                   | 3. A. inversely. As a loaf of bread ages, its freshness decreases.                                                        |
| 4. Which of the following is an appropriate unit for area?<br>A. seconds<br>B. yards<br>C. inches<br>D. $\text{cm}^3$<br><input checked="" type="radio"/> E. square yards        | 4. E. square yards. Area is measured in units of length squared. The area that carpet covers is measured in square yards. |
| 5. Which of the following is <i>not</i> an appropriate unit for volume?<br>A. cubic miles<br>B. gallons<br><input checked="" type="radio"/> C. cm<br>D. $\text{cm}^3$<br>E. pint | 5. C. cm. Volume is measured in units of length cubed. Centimeters is simply a measure of length.                         |

| Questions                                                                                                            | Answers                                                                                                                                                                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6. All of the following are measures of length <b>except</b> :<br>A. mile<br>B. inch<br>C. mm<br>D. second<br>E. km  | 6. D. second. Seconds are units of time, not length.                                                                                                                                                                                                               |
| 7. List these metric terms in increasing order:<br>A. mega<br>B. micro<br>C. milli<br>D. hecto<br>E. deca<br>F. deci | 7. The correct sequence of increasing order is as follows: B, C, F, E, D, A, or micro, milli, deci, deca, hecto, mega.                                                                                                                                             |
| 8. List these metric terms in decreasing order:<br>A. nano<br>B. centi<br>C. giga<br>D. kilo<br>E. hecto<br>F. micro | 8. The correct sequence of decreasing order is as follows: C, D, E, B, F, A, or giga, kilo, hecto, centi, micro, nano.                                                                                                                                             |
| 9. How many milliliters are in 8 liters?<br>A. 1/8<br>B. 8<br>C. 80<br>D. 800<br>E. 8000                             | 9. E. 8000. Milli means thousandth. One liter contains 1,000 milliliters. Thus, 8 liters contain 8,000 ml. With questions such as this, as the metric prefix gets smaller, the number must increase. When the metric prefix gets larger, the number must decrease. |
| 10. How many centimeters are in 3 meters?<br>A. 1/300<br>B. 1/3<br>C. 3<br>D. 300<br>E. 3000                         | 10. D. 300. Centi means hundredth. There are 100 centimeters in 1 meter. Thus, there are 300 cm in 3 meters.                                                                                                                                                       |

| Questions                                                                                                               | Answers                                                             |
|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| 11. How many kilometers are in 3000 meters?<br>A. 1/300<br>B. 1/3<br>C. 3<br>D. 300<br>E. 3000                          | 11. C. 3. Kilo means thousand. Three kilometers equal 3,000 meters. |
| 12. What is the reciprocal of 100?<br>A. 0.1<br>B. 100<br>C. 0.2<br>D. 0.01<br>E. 1/50                                  | 12. D. The reciprocal of 100 is $1/100$ or 0.01.                    |
| 13. What is the reciprocal of $1/8$ ?<br>A. 80<br>B. 10<br>C. 1<br>D. 8<br>E. 72                                        | 13. D. The reciprocal of $1/8$ is 8.                                |
| 14. How many hertz is 3 MHz?<br>A. 3,000,000<br>B. 3000<br>C. 333<br>D. 0.003                                           | 14. A. 3,000,000.                                                   |
| 15. How many milliliters are contained in a jar filled with 5 liters of fluid?<br>A. 5<br>B. 5000<br>C. 500<br>D. 0.005 | 15. B. 5000.                                                        |
| 16. How many liters are contained in 80 ml of fluid?<br>A. 8<br>B. 80<br>C. 0.008<br>D. 0.080                           | 16. D. 0.080<br><i>.080</i>                                         |



| Questions                                                                                                              | Answers                                                |
|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|
| 17. How much bigger is a thousand than ten?<br>A. 10 times<br>B. 100 times<br>C. 1000 times<br>D. 500 times            | 17. B. A thousand is 100 times bigger than ten.        |
| 18. How much bigger is a billion than a million?<br>A. 10 times<br>B. 100 times<br>C. 1000 times<br>D. 500 times       | 18. C. A billion is 1000 times greater than a million. |
| 19. How much smaller is a hundred than a thousand?<br>A. 1/10<br>B. 1/100 times<br>C. 1/1000 times<br>D. 1/10000 times | 19. A. A hundred is one-tenth of a thousand.           |

Match the appropriate term in the first column with the units in the second column.

| Term           | Units                |
|----------------|----------------------|
| 1. time        | A. 6 square miles    |
| 2. length      | B. -9 degrees        |
| 3. cost        | C. 14 kilograms      |
| 4. volume      | D. 83%               |
| 5. area        | E. 15 m <sup>3</sup> |
| 6. test score  | F. 12 centimeters    |
| 7. mass        | G. 4 minutes         |
| 8. temperature | H. 86 cents          |

| Answers |
|---------|
| 1. G    |
| 2. F    |
| 3. H    |
| 4. E    |
| 5. A    |
| 6. D    |
| 7. C    |
| 8. B    |

# Sound

In diagnostic ultrasonography, **sound pulses created by a transducer travel through biologic tissue, or media.** Reflections arising from boundaries between structures in the body return to the transducer and are processed into images.

## Sound Waves

All waves **carry energy** from one location to another. Many different forms of waves exist, including heat, sound, magnetic, and light.

Sound is a **mechanical wave** in which particles in the medium move. The molecules in the medium vibrate back and forth from a fixed position.

✱ Sound cannot travel through a vacuum; it must travel through a medium, where molecules are alternately **compressed** (squeezed together) and **rarefied** (stretched apart).

Sound travels in a **straight line**.

Sound waves are **longitudinal waves**.

### Acoustic propagation properties

The effects of the medium upon the sound wave.

### Biologic effects

The effects of the sound wave upon the biologic tissue through which it passes.



## Acoustic Variables

Sound waves are identified by oscillations in acoustic variables. **Three acoustic variables—pressure, density, and distance**—are used to distinguish between sound waves and other types of waves.

If one of these acoustic variables has a rhythmic oscillation, then the wave is a sound wave. If something other than pressure, density, or distance (particle motion) rhythmically oscillates in a wave, then the wave is *not* a sound wave.

Sound waves are also known as **acoustic waves**.

**Table 2.1** Acoustic Variables Identify Sound Waves

| Acoustic Variable | Units              |
|-------------------|--------------------|
| pressure          | pascals (Pa)       |
| density           | kg/cm <sup>3</sup> |
| distance          | cm, mm             |

## Acoustic Parameters

After a wave is identified as a sound wave, it is important to describe the wave's features.

Seven acoustic parameters are used to accurately describe the characteristics of a sound wave (see Table 2.2). A detailed description of the seven acoustic parameters appears in Chapter 3, *Describing Sound Waves*.

### Pressure

Concentration of force in an area.

**Units:** pascals (Pa)

### Density

Concentration of mass in a volume.

**Units:** kg/cm<sup>3</sup>

### Distance

Measure of particle motion.

**Units:** cm, feet, mile.

**Table 2.2** Acoustic Parameters Describe Sound Waves

| Seven Acoustic Parameters |                   |
|---------------------------|-------------------|
| •                         | Period            |
| •                         | Frequency         |
| •                         | Amplitude         |
| •                         | Power             |
| •                         | Intensity         |
| •                         | Wavelength        |
| •                         | Propagation speed |

## Transverse Waves

In a **transverse wave**, particles move in a direction that is perpendicular (at right angles) to the direction that the wave propagates (see Fig. 2.1).

Holding the end of a string and shaking it up and down creates a transverse wave. Although the string moves up and down, the energy from the oscillations moves in a perpendicular direction and away from your hand.

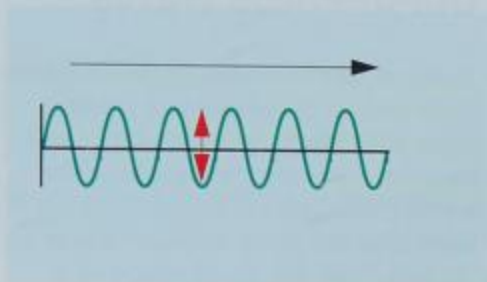


**Fig. 2.1** Example of a transverse wave. The wave is moving from left to right (black arrow); however, the particles in the wave are moving up and down (red arrow).

## Longitudinal Waves

In a **longitudinal wave**, particles move in the same direction that the wave propagates. Sound is a longitudinal wave (see Fig. 2.2).

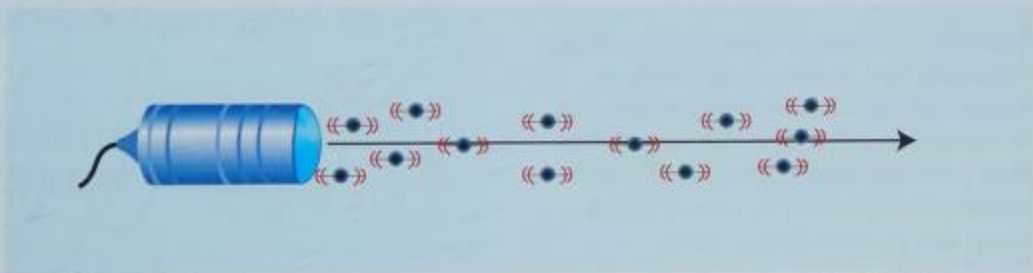


**Fig. 2.2** Example of a longitudinal wave. The wave is moving from left to right (black arrow). The particles in the wave are moving along in the same direction back and forth, from left to right and then from right to left. Sound waves are longitudinal.

## In-Phase and Out-of-Phase Waves

A pair of waves are considered **in-phase** when their peaks (maximum values) occur at the same time and at the same location. Similarly, the troughs of the waves (minimum values) occur at the same time and place. In-phase waves are “in step,” just like the members of a synchronized marching band (see Fig. 2.3).

In contrast, when two waves are **out-of-phase**, their peaks occur at different times, and so do their troughs: they are “out of step” (see Fig. 2.4).

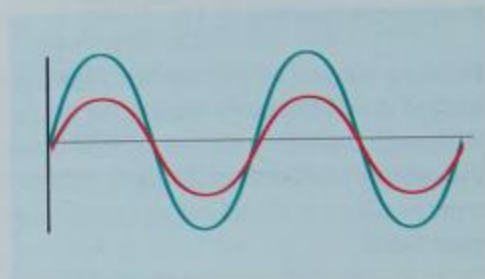


Fig. 2.3 A pair of in-phase waves.

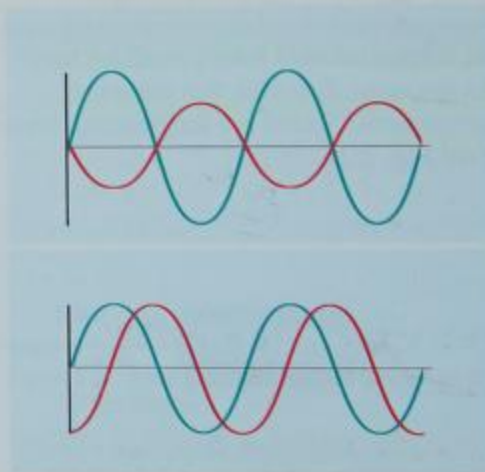


Fig. 2.4 Two examples of out-of-phase waves.

## Interference

More than one sound beam may travel in a medium and, on occasion, multiple beams may arrive at an identical location at exactly the same time. The waves lose their individual characteristics at that moment and combine to form a single wave: this combination is called **interference**.

Both in-phase and out-of-phase wave pairs undergo interference; however, they combine differently.

Interference of waves may be described in two ways, depending upon the phase relationship of the pair of waves.



## Constructive Interference

The interference of a pair of **in-phase waves** results in the formation of a single wave of greater amplitude than either of its components. This combination is called **constructive interference**, where the resulting wave is larger than either of its components (see Fig. 2.5).

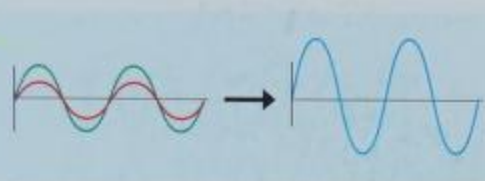


Fig. 2.5 Constructive interference takes place with in-phase waves.

## Destructive Interference

The interference of a pair of **out-of-phase waves** results in the formation of a single wave of lesser amplitude than at least one of its components. This combination is called **destructive interference**, where the resultant wave is smaller than one of its components (see Fig. 2.6).



Fig. 2.6 Destructive interference takes place with out-of-phase waves.

When two out-of-phase waves are of equal amplitude, complete destructive interference may occur (see Fig. 2.7).

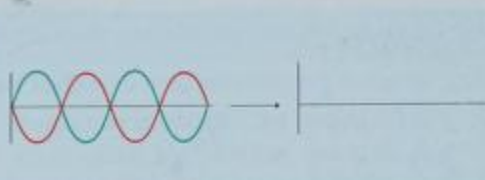


Fig. 2.7 Out-of-phase waves of equal amplitude may cancel each other out.

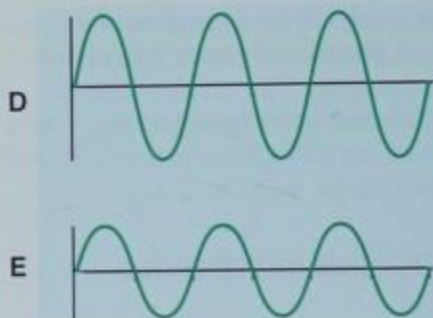
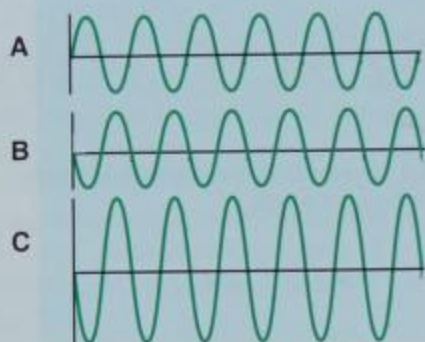
## Interference of Waves with Different Frequencies

An interesting phenomenon occurs when waves of different frequencies interfere. At some moment in time, the waves are in phase and the interference is **constructive**, while at other moments, the waves are out of phase and the interference is **destructive**. Therefore, when the frequencies of the waves differ, **both constructive and destructive interference** occur (see Fig. 2.8).



Fig. 2.8 Interference pattern of waves with different frequencies.

## Review: Sound



| Questions                                                                                                                                                                                                                                             | Answers |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 1. Which of the following best describes waves A and B?<br>A. in phase, will interfere constructively<br>B. in phase, will interfere destructively<br>C. out of phase, will interfere constructively<br>D. out of phase, will interfere destructively | 1. D    |
| 2. Which of the following best describes waves B and C?<br>A. in phase, will interfere constructively<br>B. in phase, will interfere destructively<br>C. out of phase, will interfere constructively<br>D. out of phase, will interfere destructively | 2. A    |
| 3. Which of the following best describes waves A and C?<br>A. in phase, will interfere constructively<br>B. in phase, will interfere destructively<br>C. out of phase, will interfere constructively<br>D. out of phase, will interfere destructively | 3. D    |
| 4. Which of the following best describes waves D and E?<br>A. in phase, will interfere constructively<br>B. in phase, will interfere destructively<br>C. out of phase, will interfere constructively<br>D. out of phase, will interfere destructively | 4. A    |



| Questions                                                                                                                                                                                                                                                       | Answers                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| 5. What do waves transfer from one location to another?<br>A. matter<br>B. molecules<br>C. energy<br>D. water                                                                                                                                                   | 5. C. Waves carry energy from place to place.                    |
| 6. Which of the following best describes sound waves?<br>A. a series of compressions and rarefactions<br>B. waves that are heard by man<br>C. movement of molecules and energy from one location to another<br>D. waves that are used to make images of anatomy | 6. A. Sound waves are a series of compressions and rarefactions. |
| 7. Which of the following terms does not belong with the others?<br>A. compression<br>B. region of high density<br>C. region of high pressure<br>D. wide molecular spacing                                                                                      | 7. D                                                             |
| 8. Variations in all of the following identify specific waves as acoustic waves <b>except</b> .<br>A. pressure<br>B. parameters<br>C. density<br>D. acoustic variables                                                                                          | 8. B                                                             |
| 9. All of the following are true of sound waves <b>except</b> .<br>A. they are acoustic<br>B. they are pressure waves<br>C. they are transverse<br>D. they move energy                                                                                          | 9. C. Sound waves are longitudinal, not transverse.              |
| 10. All of the following are acoustic parameters <b>except</b> .<br>A. pressure<br>B. period<br>C. propagation speed<br>D. frequency                                                                                                                            | 10. A. Pressure is an acoustic variable, not a parameter.        |

| Questions                                                                                                                                                                                                               | Answers                                                                                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| 11. Which of the following best describes sound waves?<br>A. transverse, pressure waves<br>B. transverse, longitudinal waves<br>C. longitudinal, out-of-phase waves<br>D. longitudinal, pressure waves                  | 11. D                                                                                               |
| 12. Two waves are traveling in a medium and arrive at a location at the same time. What event takes place?<br>A. constructive interference<br>B. destructive interference<br>C. interference<br>D. reflection           | 12. C                                                                                               |
| 13. Which types of waves will exhibit both constructive and destructive interference?<br>A. waves of different amplitude<br>B. a pair of longitudinal waves<br>C. waves of different frequency<br>D. out-of-phase waves | 13. C. Both constructive and destructive interference occurs with waves with different frequencies. |
| 14. What units are used to report the pressure of a sound beam?<br>A. pounds<br>B. centimeters<br>C. pascals<br>D. kg/cm                                                                                                | 14. C. Pressure is appropriately reported with units of pascals, abbreviated Pa.                    |
| 15. True or False? Acoustic variables allow us to determine which waves are sound waves and which are not.                                                                                                              | 15. True.                                                                                           |
| 16. True or False? Acoustic parameters are used to describe the features of sound waves.                                                                                                                                | 16. True.                                                                                           |

# Describing Sound Waves

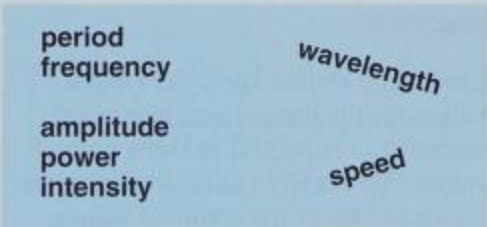
## Introduction

**Parameters describe features of a sound wave.** The values of seven parameters are required to completely characterize a sound wave.

It is not enough to learn the meaning of the parameters; you must know which units are used to report values of the parameters. For example, the units associated with age can be any unit of time such as years, seconds, minutes, or decades. The units associated with height can be inches, feet, meters, or miles.

Sometimes, parameters have synonyms, and it is essential to know all the names for these parameters.

As introduced in the previous chapter, the seven parameters that completely describe sound waves appear in Fig. 3.1. At the end of your studies, you will understand this peculiar arrangement, and how it helps you to organize and recall the material effectively.



period  
frequency  
amplitude  
power  
intensity  
wavelength  
speed

**Fig. 3.1** Seven parameters describe sound waves.

If you know whether the parameter is determined by the sound source or the medium, you will be able to understand how these parameters relate to the physical principles of ultrasound physics.

The **source** of a sound wave is the ultrasound system and transducer. The quantity, or level, of some of the parameters are established by the ultrasound system. The sonographer can adjust the level of some of these parameters, whereas others cannot be changed.

Other parameters are determined by the tissue through which the sound is traveling. The tissue is also called the **medium**.

It is important to know whether the sonographer has the ability to change the value of a parameter while using a particular transducer. In other words, is there a knob or control on the system that will allow you to alter the parameter's magnitude?

Lastly, you should know the typical values for the parameters. In clinical medicine, it is helpful to know normal values. Similarly, in ultrasound physics, we should know the common values.

## Period

### Period

Period is the time it takes a wave to vibrate a single cycle, or the time from the start of one cycle to the start of the next cycle.

### Units

Period is reported in units of time, such as microseconds ( $\mu\text{s}$ ), seconds, hours, or days.

### Typical Values

The typical value of period in diagnostic ultrasound is 0.06 to 0.5 microseconds ( $\mu\text{s}$ ). This may also be written as:

$6 \times 10^{-8}$  to  $5 \times 10^{-7}$  seconds

0.06 to 0.5  $\mu\text{s}$

0.00000006 to 0.0000005 seconds

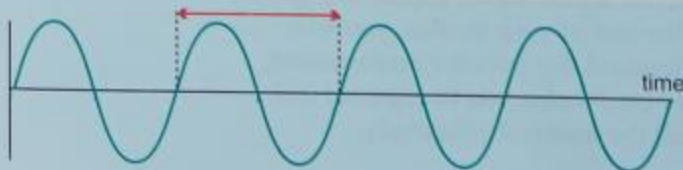
### Determined By

Period is determined by the sound source only, not by the medium.

### Adjustable

No. The sonographer cannot change the period while using a basic ultrasound system with a particular transducer.

**Fig. 3.2** The wave's period is identified by the red arrow. The period of a wave is the time necessary to create a single cycle.





# Frequency

## Frequency

Frequency is the number of particular events that occur in a specific duration of time. For example, the frequency of presidential elections in the United States is:

- twenty-five times per century
- two-and-one-half times per decade
- once every four years

In diagnostic ultrasound, the frequency of a wave is described as the number of cycles that occurs in one second.

## Units

Frequency is reported in units of per second, 1/second, hertz, or Hz. Hertz is another way to say "per second."

- 1 cycle/second = 1 hertz
- 1,000 cycles/second = 1 kHz
- 1,000,000 cycles/second = 1 MHz

## Typical Values

In clinical imaging, frequency ranges from approximately 2 MHz to 15 MHz. Another way to say this is 2 million to 15 million per second.

## Determined By

Frequency of a sound wave is determined by the **sound source** only, not by the medium through which the sound is traveling.

## Adjustable

No. The sonographer cannot change the frequency while using a basic ultrasound system and transducer.



**Fig. 3.3** In this illustration, the wave's frequency is 4 per second, or 4 Hz.



**Fig. 3.4** There are 8 cycles that occur in 4 seconds; the frequency of this wave is  $8/4$ , or 2 Hz.



## More About Frequency

### *How did ultrasound get its name?*

Sound is classified based on the ability of humans to hear it.

If the frequency of a sound wave is less than 20 Hz, it is below the threshold of human hearing and cannot be heard. That is, the sound is inaudible. Sound waves with frequencies this low are defined as **infrasonic** or **infrasound**.

Humans can hear sound with frequencies between 20 Hz and 20,000 Hz. This sound is called **audible**.

Sound with frequencies so high that humans cannot hear it is called **ultrasonic** or **ultrasound**. Ultrasound's frequency is higher than 20,000 Hz, (20 kHz).

### *Why is frequency important in diagnostic sonography?*

Frequency is important in sonography because it affects penetration and image quality. These concepts will be addressed later in this text.

### *What is the relationship between frequency and period?*

★ Period and frequency are **inversely related** to each other.

- As frequency increases, period decreases.
- As frequency decreases, period increases.

Table 3.1 Frequency Spectrum of Sound

| Sound Wave    | Frequency                |
|---------------|--------------------------|
| infrasound    | less than 20 Hz          |
| audible sound | between 20 Hz and 20 kHz |
| ultrasound    | greater than 20 kHz      |

- If one of these parameters remains constant, then the other remains unchanged.

Period and frequency have an even more special relationship that is called

**reciprocal**. When two reciprocal parameters are multiplied together, the result is 1:

$$\text{Period} \times \text{Frequency} = 1$$

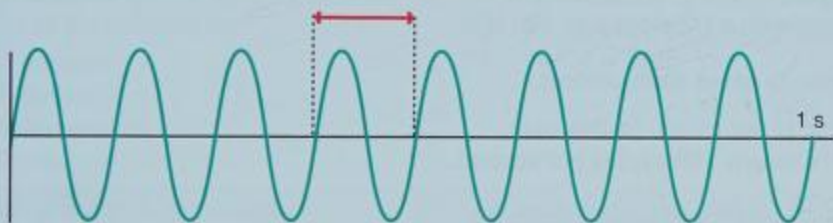


**Fig. 3.5** Reciprocal relationship between period and frequency. The frequency of this wave is 8 Hz and the period is 1/8 of a second.

For example, in Fig. 3.5, a wave takes one-eighth of a second to vibrate up and down. Thus, the period is 1/8 second and the frequency is 8 per second.

$$\frac{1}{8} \times 8 = 1$$

**Hint:** Remember to use complementary units: seconds and hertz, milliseconds and kilohertz.

## More about Hertz

Frequency is reported with units of hertz (Hz). Some people believe that hertz means “cycles per second.” This belief requires some clarification. It is more precise to think of hertz as a two-part process:

1. hertz means events per second
2. to which event are we referring?

For example, what is the meaning of a sound wave with a frequency of 100 Hz?

1. 100 events occur each second.
2. A cycle is our event. In this case, 100 Hz means 100 **cycles** per second.

What is the meaning of a flat-screen TV with a frame rate of 120 Hz?

1. 120 events occur each second.
2. A frame is our event. Thus, the TV displays 120 **frames** per second.

What is the meaning of an individual with a heart rate of 1 Hz?

1. One event occurs each second.
2. A heartbeat is the event. The individual's heart contracts at a rate of 1 **beat** per second (or 60 beats per minute).

Describing hertz in this manner will be useful as we study ultrasound physics further.

## Review: Period and Frequency

| Questions                                                                                                                              | Answers                                                                                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. What is the period of the earth's rotation around the sun?<br>A. 1 day<br>B. 1 hour<br>C. 1 month<br>D. 1 year                      | 1. D. The earth completes one cycle around the sun in one year.                                                                                   |
| 2. A top is spinning on a table. What is the period of the spinning top?<br>A. 4 pounds<br>B. 8 dollars<br>C. 0.05 seconds<br>D. 3 cm  | 2. C. Of the available answers, the only one that has units of time is 0.05 seconds. This must be the answer.                                     |
| 3. Which of the following waves is infrasonic?<br>A. 4 MHz<br>B. 400 kHz<br>C. 28 Hz<br>D. 2 Hz                                        | 3. D. A wave with a frequency less than 20 Hz cannot be heard because its frequency is less than the lower limit of human hearing.                |
| 4. Identify the wave that is ultrasonic.<br>A. 400 mHz<br>B. 4 MHz<br>C. 28 Hz<br>D. 2 Hz                                              | 4. B. A wave with a frequency greater than 20,000 Hz cannot be heard because its frequency is higher than the upper limit of human hearing.       |
| 5. Which of these waves is ultrasonic and most useful in diagnostic sonography?<br>A. 400 MHz<br>B. 4 MHz<br>C. 2 kHz<br>D. 200,000 Hz | 5. B. Although choices A, B, and D are all ultrasonic, only answer B falls within the typical range of frequencies used in diagnostic sonography. |



| Questions                                                                                                                                                        | Answers                                                                                                                                                                                                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>6. Identify all the waves that are inaudible. (More than 1 answer may be correct.)</p> <p>A. 4 MHz<br/>B. 400 kHz<br/>C. 28 Hz<br/>D. 2 Hz</p>                | <p>6. A, B, D. These 3 waves are inaudible and cannot be heard by humans. Choices A and B are ultrasonic, whereas D is infrasonic. Humans cannot hear infrasound or ultrasound.</p>                          |
| <p>7. Which of the following waves has the longest period?</p> <p>A. 2 MHz<br/>B. 4,000 Hz<br/>C. 6 Hz<br/>D. 1 kHz</p>                                          | <p>7. C. The wave with a frequency of 6 Hz has the longest period. Period and frequency have an inverse relationship. Thus, the wave with the lowest frequency has the longest period.</p>                   |
| <p>8. Of the four waves whose periods are listed below, which has the highest frequency?</p> <p>A. 8 s<br/>B. 80 <math>\mu</math>s<br/>C. 8 Ms<br/>D. 800 ks</p> | <p>8. B. The wave with a period of 80 <math>\mu</math>s has the highest frequency. Period and frequency have an inverse relationship. Thus, the wave with the shortest period has the highest frequency.</p> |
| <p>9. Of the four waves whose frequencies are listed below, which has the shortest period?</p> <p>A. 12 kHz<br/>B. 6,000 Hz<br/>C. 205 Hz<br/>D. 1 kHz</p>       | <p>9. A. Of the 4 choices, A has the highest frequency and, thus, the shortest period.</p>                                                                                                                   |
| <p>10. Of the four waves whose periods are listed below, which has the lowest frequency?</p> <p>A. 8 s<br/>B. 80 <math>\mu</math>s<br/>C. 8 Ms<br/>D. 800 ks</p> | <p>10. C. The wave with the longest period has the lowest frequency. Choice C has a period of 8 million seconds (8 Ms), which is the longest period.</p>                                                     |



## Three “Bigness” Parameters

Three parameters describe the size, **magnitude**, or strength of a sound wave:

1. amplitude
2. power
3. intensity

### 1. Amplitude

#### Amplitude

Amplitude is the “bigness” of a wave. It is the difference between the maximum value and the average or undisturbed value of an acoustic variable. Amplitude is also the difference between the minimum value and the average value of the acoustic variable.

#### Units

Amplitude can have units of any of the acoustic variables (see “Acoustic Variables” on page 12):

- pressure—pascals
- density— $\text{g/cm}^3$
- particle motion—cm, inches—any distance

Amplitude, in relative terms, can also be expressed in decibels (dB).

#### Typical Values

In clinical imaging, pressure amplitude ranges from 1 million pascals (1 MPa) to 3 million pascals (3 MPa).

Table 3.2 Describing the Magnitude of a Sound Wave

#### Bigness Parameters

- Amplitude
- Power
- Intensity

#### Determined By

Initially, amplitude is determined only by the **sound source**, the ultrasound system. However, amplitude decreases as sound propagates through the body. The rate at which amplitude decreases as sound propagates depends on the characteristics of both the sound wave and the medium.

#### Adjustable

Yes, a control on a basic ultrasound system allows the sonographer to alter initial amplitude of a wave.

## More About Amplitude

*What is the difference between amplitude and peak-to-peak amplitude?*

**Amplitude** is measured from the middle, or undisturbed, value to the maximum value (see Fig. 3.6).

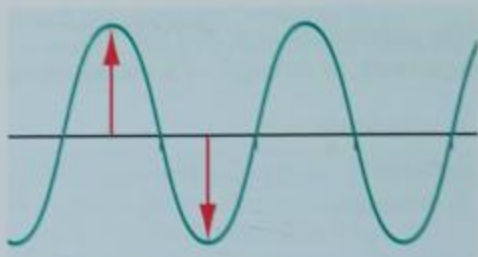


**Fig. 3.6** Amplitude of a wave. Note that the amplitude is measured from the baseline to the maximum, or from the baseline to the minimum.

**Peak-to-peak amplitude** is the difference between maximum and minimum values of an acoustic variable. Therefore, peak-to-peak amplitude is twice the value of the amplitude (see Fig. 3.7).

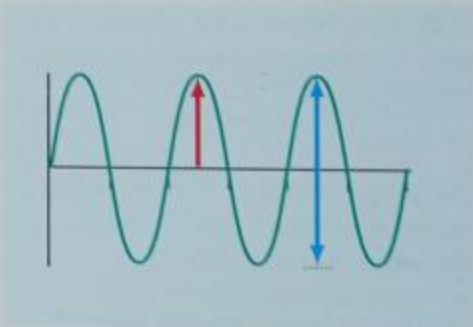


**Fig. 3.7** Compare peak-to-peak amplitude (blue) and amplitude (red). Peak-to-peak amplitude is twice that of amplitude.

## 2. Power

### Power

Power is the rate of energy transfer or the rate at which work is performed. Power, like amplitude, describes the “bigness” of a wave.

### Units

Power has units of **watts**.

### Typical Values

In clinical imaging, typical powers range from **0.004 to 0.090 watts** (4 to 90 milliwatts), depending on the diagnostic ultrasound technique.

**Hint:** When you think of power, think of a light bulb!

### Determined By

Just like amplitude, initial power is determined only by the **sound source**, the ultrasound system. Power decreases as sound propagates through the body.

The rate at which power decreases as sound propagates depends on the characteristics of the medium and the wave.

### Adjustable

Yes, initial power, like amplitude, can be changed. A control on ultrasound systems allows the sonographer to alter the initial power of a wave.

## More About Power

### *How are amplitude and power related?*

Both amplitude and power are parameters that describe the size, or magnitude, of a wave. When power increases, so does amplitude. Similarly, when power decreases, amplitude decreases.

Mathematically, power is proportional to the wave's amplitude squared. The term **squared** means that a number is multiplied by itself.

$$\text{power} \propto \text{amplitude}^2$$

**Hint:** The symbol  $\propto$  means proportional to.

**Examples**

*A sonographer increases the amplitude of a wave by a factor of 3. How has the power changed?*

Recall that power is proportional to the amplitude squared:

$$3 \times 3 = 9$$

Thus, the power is increased 9-fold. In other words, if the amplitude is increased by a factor of 3, the power is increased by a factor of 9.

*When a sonographer decreases the amplitude of a wave to  $\frac{1}{2}$  of its original value, how has the power changed?*

Recall that power is proportional to the amplitude squared:

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Thus, the power is decreased to  $\frac{1}{4}$ , or 25%, of its original value. In other words, when the amplitude is decreased by a factor of 2, the power is decreased by a factor of 4.



### 3. Intensity

#### Intensity

Intensity is the concentration of energy in a sound beam. To calculate intensity, divide the beam's power by the beam's cross-sectional area.

Intensity, like power and amplitude, describes the "bigness" of a wave.

Intensity relates to how the power in a wave spreads or is distributed in space. Therefore, intensity depends on both the power in the beam and the area over which the power is applied.

#### Units

The units of intensity are watts/square centimeter, or  $\text{W}/\text{cm}^2$  (watts from power and  $\text{cm}^2$  from beam area).

#### Typical Values

In clinical imaging, intensity ranges from 0.01 to 300  $\text{W}/\text{cm}^2$ .

#### Determined By

Just like amplitude and power, initial intensity is determined only by the **sound source**, the ultrasound system. Intensity changes as sound propagates through the body.

The rate at which intensity changes as sound propagates depends on the characteristics of both the sound wave and the medium.

#### Adjustable

Yes. Initial intensity, like power and amplitude, can be changed. A control on a basic ultrasound systems allows the sonographer to alter the initial intensity of a wave.

$$\text{intensity (W/cm}^2\text{)} = \frac{\text{power (w)}}{\text{area (cm}^2\text{)}} \quad \star$$



## More About Intensity

Amplitude, power, and intensity are three parameters that describe the magnitude or strength of a wave. These parameters tend to be directly related; therefore, when intensity increases, power and amplitude also increase.

*How is intensity related to power and amplitude?*

### Relationship between Intensity and Power

Mathematically, intensity is proportional to power.

$$\text{intensity} \propto \text{power}$$

#### Examples

- When a wave's power is doubled, the intensity is doubled.
- When a wave's power is quartered, the intensity is quartered.

### Relationship between Intensity and Amplitude

Mathematically, intensity is proportional to the wave's amplitude squared. The term "squared" means that a number is multiplied by itself.

$$\text{intensity} \propto \text{amplitude}^2$$

#### Example

When a wave's amplitude is doubled, the intensity increases to four times its original value.

$$2 \times 2 = 4$$

**Hint:** When discussing relationships between amplitude, power, and intensity, the word **squared** always follows the word **amplitude**.

- Power is related to the *amplitude squared*.
- Intensity is related to the *amplitude squared*.
- Power is related to the intensity.

Remember—*Amplitude Squared*.

# Wavelength

## Wavelength

Wavelength is the distance or length of one complete cycle. For example, imagine a sound wave as similar to a train. Wavelength is the length of a single boxcar in a train.

## Units

Wavelength is measured in units of mm, meters, or any other unit of length.

## Typical Values

In clinical imaging, wavelength in soft tissue ranges from 0.1 to 0.8 mm.

## Determined By

Wavelength is determined by **both the source and the medium**.

## Adjustable

No, wavelength cannot be changed by the sonographer when using a basic ultrasound transducer.

**Hint:** Wavelength is the only parameter that is determined by both the source and the medium.

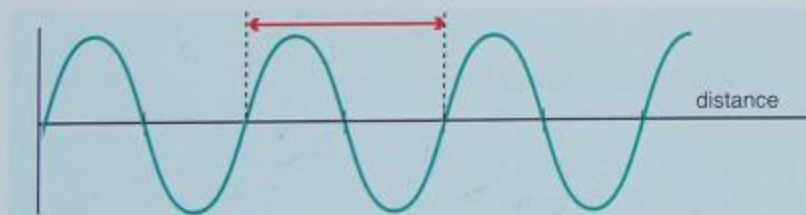


**Fig. 3.8** The wavelength is identified by the red arrow. The wavelength is the distance that a single cycle occupies in space.

## More About Wavelength

### *What is the difference between wavelength and period?*

Period is illustrated in Fig. 3.2 and wavelength is illustrated in Fig. 3.8. These figures appear to be identical, but they are not.

Both wavelength and period describe a single cycle in a sound wave. Wavelength refers to the length or distance of a single cycle. Period refers to the time that it takes to complete a single cycle. Wavelength and period are differentiated by their units; wavelength has units of distance, whereas period has units of time.

### *What is the relationship between wavelength and frequency?*

As long as a wave remains in one medium, wavelength and frequency are inversely related. As frequency increases, wavelength decreases. The lower the frequency, the longer the wavelength (see Fig. 3.9).

For example, if a wave's frequency is twice that of another, the wavelength will be half as much.

### *What is the wavelength of 1 MHz sound in soft tissue?*

In soft tissue, sound with a frequency of 1 MHz has a wavelength of 1.54 mm.

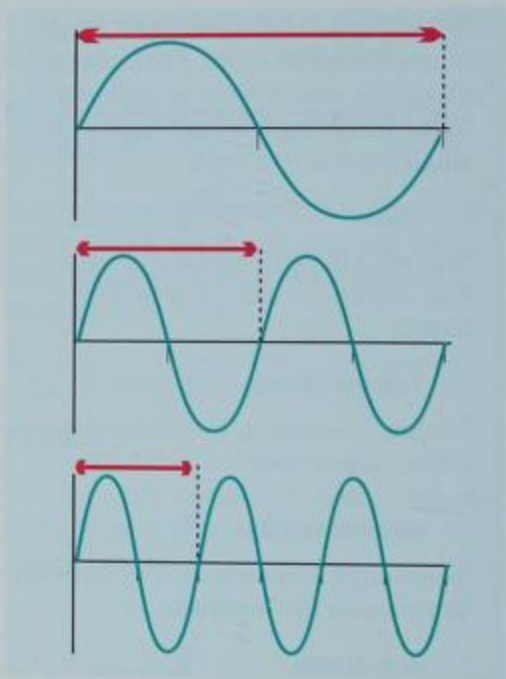


**Fig. 3.9** Wavelength of three different frequency sound waves in soft tissue. Wavelength is inversely proportional to frequency; as frequency increases, wavelength decreases.

***What is the wavelength of other frequency sound waves in soft tissue?***

Sound with a frequency of 2 MHz has a wavelength of 0.77 mm in soft tissue:

$$\frac{1.54 \text{ mm}}{2} = 0.77 \text{ mm}$$

***What is the rule that defines the relationship between frequency and wavelength of sound in soft tissue?***

To find the wavelength of a sound wave in soft tissue, divide 1.54 mm by the frequency in MHz: 

$$\text{wavelength (mm)} = \frac{1.54 \text{ mm}/\mu\text{s}}{\text{frequency (MHz)}}$$

***Why is wavelength important in diagnostic ultrasound?***

Wavelength plays a very important role in image quality. Shorter wavelengths are created by high frequency sound. This usually produces higher quality images with greater detail. Therefore, sonographers should try to use higher frequency transducers rather than lower frequency transducers.



# Propagation Speed

## Propagation Speed

Propagation speed is the rate at which a sound wave travels through a medium.

### Units

Speed is measured in units of meters per second, mm/ $\mu$ s, or any distance divided by time.

### Typical Values

In the body, the speed of sound ranges from 500 m/s to 4000 m/s, **depending on the tissue** through which it is traveling.

### Determined By

Speed is determined only by the **medium** through which the sound is traveling. Speed is not affected by the nature of the sound wave.

All sound, regardless of the frequency, travels at the same speed through any specific medium. This means that sound with a frequency of 5 MHz and sound with a frequency of 3 MHz travel at the same propagation speed in the same medium.

### Adjustable

No, speed of sound cannot be changed by the sonographer. Speed changes only when the wave travels from one medium to a different medium.

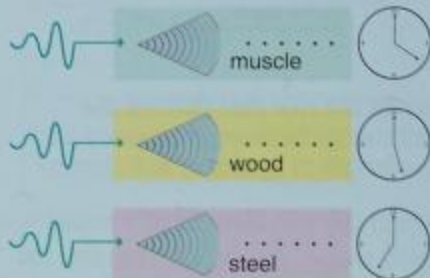


**Fig. 3.10** Identical acoustic waves travel at unequal speeds through different media. The propagation speed depends upon the density and stiffness (elastic properties) of each medium.

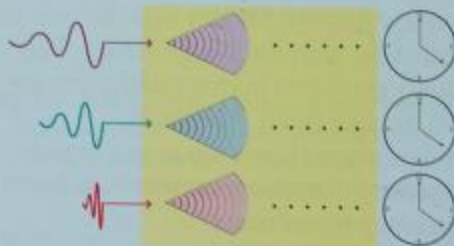


**Fig. 3.11** All acoustic waves, even those with different frequencies, travel at the same speed through a particular medium. In a single medium, all sound waves travel at the same speed.



## More About Speed

### *What is the speed of sound in soft tissue?*

The average or typical biologic medium is called soft tissue. The speed of sound in soft tissue is **1,540 m/s**. Other ways to report this value are 1.54 mm/ $\mu$ s or 1.54 km/s. This value is approximately 1 mile per second!

### *What is the speed of sound in biologic tissues other than soft tissue?*

Table 3.3 Speed of Sound in Biologic Media

| Tissue Type                  | Speed (m/s)  |
|------------------------------|--------------|
| Lung                         | 500          |
| Fat                          | 1,450        |
| <b>Soft Tissue (average)</b> | <b>1,540</b> |
| Liver                        | 1,560        |
| Blood                        | 1,560        |
| Muscle                       | 1,600        |
| Tendon                       | 1,700        |
| Bone                         | 3,500        |

### *What is the speed of sound in other media?*

Table 3.4 Speed of Sound in Other Materials

| Material | Speed (m/s)    |
|----------|----------------|
| Air      | 330            |
| Water    | 1,480          |
| Metals   | 2,000 to 7,000 |

**Hint:** As a general rule, sound travels fastest in solids, slower in liquids, and slowest in gases.

$$\text{speed (m/s)} = \text{frequency (Hz)} \times \text{wavelength (m)}$$

## What characteristics of a medium determine the speed of sound in that medium?

Two characteristics of a medium affect the speed of sound:

- stiffness
- density

### Stiffness

Stiffness describes the ability of an object to resist compression. In other words, what will happen if the material is squeezed? A stiff material will retain its shape, whereas a non-stiff material will change its shape. A ping-pong ball is stiff, whereas a marshmallow is not.

### Density

Density describes the relative weight of a material. When equal volumes of two materials are compared, the dense material weighs a lot, whereas the non-dense material weighs little. Steel is dense, aluminum is not dense.

#### How does stiffness affect speed?

*Stiffness and speed are directly related.* As materials become stiffer, the speed of sound in the material increases. In two otherwise identical media, the speed of sound will be higher in the stiffer medium.

#### What other terms describe stiffness?

*Bulk modulus* is the same as stiffness. *Elasticity* and *compressibility* are the opposite of stiff. A marshmallow may be described as not stiff, a low bulk modulus, highly elastic, or highly compressible.

#### How does density affect speed?

*Density and speed are inversely related.* As materials become more dense (heavier), the speed of sound in the material decreases. Sound travels faster in media with low density.

If two media are equally stiff, the denser medium will have a lower speed.

### How can I remember this easily?

Speed is determined by the **density and stiffness** of the medium. To remember this, use these **Rules of Thumb**:

#### Stiffness and Speed

Both words start with the same letter: S and S. They go in the same direction; **when stiffness increases, speed increases.**

#### Density and Speed

The words start with different letters, D and S. They go in different directions; **when density increases, speed decreases.**

Materials that are *stiff but not dense* will have the fastest speed. For example, bone is very stiff and not particularly dense. Therefore, sound travels fast in bone.

Materials that are *not stiff and very dense* will have the slowest speed.

### Which factor is more important?

Although both stiffness and density affect propagation speed, stiffness has the greatest influence on speed. For example, air has an exceedingly low stiffness. Therefore, sound travels slowly in air.



Fig. 3.12 Rules of Thumb



## Summary

You have previously seen the organization in Fig. 3.13 for the seven parameters that describe sound waves (see page 19). The figure is now labeled.

The **five parameters** on the left are all initially determined by the **sound source** only.

- **Period** and **frequency** are bundled together because they are reciprocals.
- The three parameters on the bottom left, **amplitude**, **power** and **intensity**, are grouped because they all describe the magnitude of the sound wave. These “bigness” parameters are the only ones that the sonographer can adjust.

**Wavelength** is alone on the right because it is the only parameter determined by both the sound source and the medium.

**Speed** is alone on the right because it is the only parameter determined solely by the medium through which sound travels.

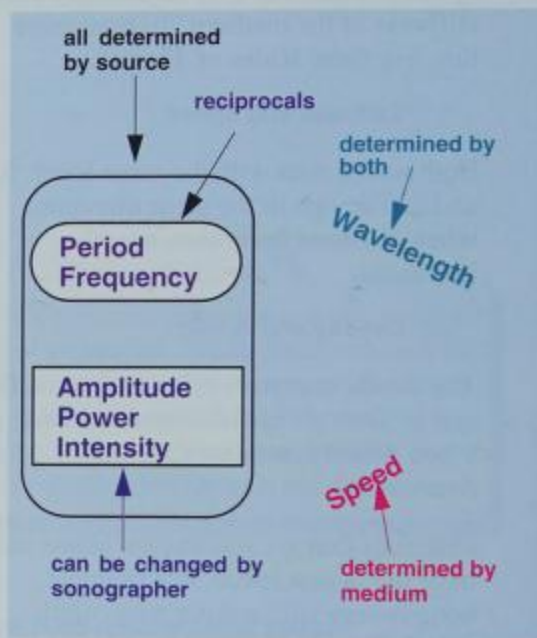


Fig. 3.13 Parameters that describe sound waves.

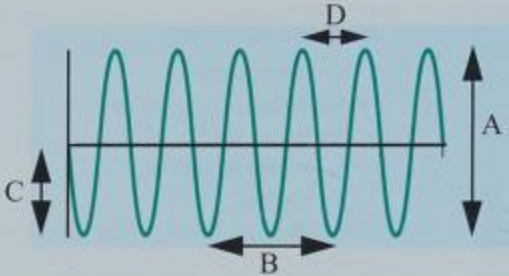
Table 3.5 Parameters of Continuous Waves

| Parameter  | Adjustable | Units                               | Determined By | Typical Value                 |
|------------|------------|-------------------------------------|---------------|-------------------------------|
| period     | no         | seconds, $\mu$ s, time              | source        | 0.06 to 0.5 $\mu$ s           |
| frequency  | no         | per second, Hz                      | source        | 2 to 15 MHz                   |
| amplitude  | yes        | pascals, cm, g/cm <sup>3</sup> , dB | source        | 1 MPa to 3 MPa                |
| power      | yes        | watts, dB                           | source        | 4 to 90 mW                    |
| intensity  | yes        | watts/cm <sup>2</sup> , dB          | source        | 0.01 to 300 W/cm <sup>2</sup> |
| wavelength | no         | mm, distance                        | both          | 0.1 to 0.8 mm                 |
| speed      | no         | m/s                                 | medium        | 1,500 to 1,600 m/s            |



## Review: Describing Sound Waves

| Questions                                                                                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. What are the units of:</p> <ul style="list-style-type: none"> <li>wavelength</li> <li>frequency</li> <li>intensity</li> <li>propagation speed</li> <li>period</li> <li>power</li> </ul>                                                                                                                      | <p>1. Units are as follows:</p> <ul style="list-style-type: none"> <li>millimeters</li> <li>hertz</li> <li>Watts/cm<sup>2</sup></li> <li>meters/second</li> <li>second</li> <li>Watts</li> </ul>                             |
| <p>2. Does the medium or the sound source determine these parameters?</p> <ul style="list-style-type: none"> <li>wavelength</li> <li>frequency</li> <li>intensity (initial)</li> <li>propagation speed</li> <li>period</li> <li>power (initial)</li> <li>amplitude (initial)</li> </ul>                            | <p>2. Parameters are determined by:</p> <ul style="list-style-type: none"> <li>both</li> <li>sound source</li> <li>sound source</li> <li>medium</li> <li>sound source</li> <li>sound source</li> <li>sound source</li> </ul> |
| <p>3. Using a particular ultrasound system and transducer, which of the following cannot be changed by the operator?</p> <ul style="list-style-type: none"> <li>wavelength</li> <li>frequency</li> <li>intensity</li> <li>propagation speed</li> <li>period</li> <li>power</li> <li>amplitude (initial)</li> </ul> | <p>3. The following can or cannot be changed:</p> <ul style="list-style-type: none"> <li>cannot</li> <li>cannot</li> <li>can</li> <li>cannot</li> <li>cannot</li> <li>can</li> <li>can</li> </ul>                            |
| <p>4. True or False. A wave with a frequency of 15,000 MHz is ultrasonic.</p>                                                                                                                                                                                                                                      | <p>4. True. Ultrasound is defined as any wave with a frequency greater than 20,000 hertz. 15,000 MHz is a frequency of 15,000,000,000 Hz!</p>                                                                                |
| <p>5. True or False. If the amplitude of a wave is increased to 3 times its original value, the intensity is increased by 6 times.</p>                                                                                                                                                                             | <p>5. False. Intensity is proportional to the amplitude squared. If we triple the amplitude, we increase the intensity by a factor of nine.</p>                                                                              |

| Questions                                                                                                                                                                                          | Answers                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Use the following graph to answer questions 6 through 12.                                                                                                                                          |                                                                     |
|                                                                                                                   |                                                                     |
| <p>6. Which of the following best describes the line identified by the letter A?</p> <p>A. amplitude<br/>B. period<br/>C. frequency<br/>D. wavelength<br/>E. peak-to-peak amplitude</p>            | <p>6. E. Peak-to-peak amplitude.</p>                                |
| <p>7. Which of the following best describes the line identified by the letter B?</p> <p>A. amplitude<br/>B. peak-to-peak amplitude<br/>C. frequency<br/>D. wavelength<br/>E. none of the above</p> | <p>7. E. None of the above. Line B is actually two wavelengths.</p> |
| <p>8. Which of the following best describes the line identified by the letter C?</p> <p>A. amplitude<br/>B. peak-to-peak amplitude<br/>C. frequency<br/>D. wavelength<br/>E. none of the above</p> | <p>8. A. Amplitude.</p>                                             |
| <p>9. Which of the lines above, A, B, C, or D, is most likely to be the reciprocal of frequency?</p>                                                                                               | <p>9. D.</p>                                                        |

| Questions                                                                                                                                                                                                                                | Answers                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| <p>10. Which of the following best describes the line identified by the letter D?</p> <p>A. amplitude<br/>B. peak-to-peak amplitude<br/>C. frequency<br/>D. wavelength<br/>E. none of the above</p>                                      | <p>10. D. Wavelength.</p>                                                                                                                   |
| <p>11. Which of the following best describes the line identified by the letter D?</p> <p>A. amplitude<br/>B. peak-to-peak amplitude<br/>C. frequency<br/>D. period<br/>E. none of the above</p>                                          | <p>11. D. Period.</p>                                                                                                                       |
| <p>12. Which of the lines above, A, B, or C, is most likely to be determined by the source and the medium?</p>                                                                                                                           | <p>12. B.</p>                                                                                                                               |
| <p>13. True or False. If the power of a wave is halved, the intensity is reduced to one-fourth its original value.</p>                                                                                                                   | <p>13. False. Intensity is the power of a beam divided by its cross-sectional area. If we halve the power, we will halve the intensity.</p> |
| <p>14. True or False. Propagation speed increases as frequency increases.</p>                                                                                                                                                            | <p>14. False. Propagation speed is determined by the medium only. Frequency and speed are unrelated.</p>                                    |
| <p>15. Medium 1 has a density of 9 and a stiffness of 6. Medium 2 has a density of 8 and a stiffness of 6. In which medium will sound travel slower?</p>                                                                                 | <p>15. Medium 1. Since both media have the same stiffness, the medium with the greater density has the lower propagation speed.</p>         |
| <p>16. Which of the following characteristics will create the fastest speed of sound?</p> <p>A. high density, high stiffness<br/>B. low density, high stiffness<br/>C. high density, low stiffness<br/>D. low density, low stiffness</p> | <p>16. B. Speed is inversely proportional to density and directly proportional to stiffness.</p>                                            |



| Questions                                                                                                                                                                                                                  | Answers                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 17. Which of the following characteristics will create the slowest speed of sound?<br>A. high density, high stiffness<br>B. low density, high stiffness<br>C. high density, low stiffness<br>D. low density, low stiffness | 17. C. Speed is inversely proportional to density and directly proportional to stiffness.                                                                                                                                                                                                                                           |
| 18. If the power in a beam is 1 watt and the area is $5 \text{ cm}^2$ , what is the beam's intensity?<br>A. $5 \text{ W/cm}^2$<br>B. $1 \text{ W/cm}^2$<br>C. $0.2 \text{ W/cm}^2$<br>D. 1 watt                            | 18. C. To answer this question, concentrate on the units. Intensity has units of $\text{W/cm}^2$ . Thus, we must find out how many watts there are, and divide them by the number of $\text{cm}^2$ . The question states that there is 1 watt. The area is $5 \text{ cm}^2$ . Thus, the intensity is 1/5, or $0.2 \text{ W/cm}^2$ . |
| 19. If intensity remains the same while the power is doubled, what has happened to the beam area?<br>A. quadrupled<br>B. doubled<br>C. halved<br>D. unchanged                                                              | 19. B. Recall that intensity equals power divided by area. If intensity remains unchanged, then whatever happens to power must also happen to area. In this case, power has doubled. Therefore, area must have doubled as well.                                                                                                     |
| 20. A sound beam travels a total of 10 cm in 2 seconds. What is the speed of the sound?<br>A. $10 \text{ cm/sec}$<br>B. $2 \text{ cm/sec}$<br>C. $5 \text{ cm/sec}$<br>D. $0.2 \text{ cm/sec}$                             | 20. C. $10 \text{ cm} / 2 \text{ sec} = 5 \text{ cm/sec}$ .                                                                                                                                                                                                                                                                         |
| 21. True or False. Propagation speed increases as frequency increases.                                                                                                                                                     | 21. False. Speed and frequency are unrelated.                                                                                                                                                                                                                                                                                       |
| 22. True or False. Propagation speed increases as frequency decreases.                                                                                                                                                     | 22. False. Speed and frequency are unrelated.                                                                                                                                                                                                                                                                                       |
| 23. True or False. Propagation speed does not change as frequency increases.                                                                                                                                               | 23. True. Propagation speed and frequency are unrelated.                                                                                                                                                                                                                                                                            |



| Questions                                                                                                                                                                                                                     | Answers                                                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>24. What is the wavelength of 3 MHz sound in soft tissue?</p> <p>A. 0.51 m<br/>B. 0.51 km<br/>C. 0.51 mm<br/>D. 0.51 nm<br/>E. 0.51 <math>\mu</math>m</p>                                                                  | <p>24. C. In soft tissue, wavelength equals 1.54 mm divided by the frequency in MHz (see page 34). Thus, 3 MHz sound will have a wavelength of 0.51 mm.</p>                                                  |
| <p>25. What is the wavelength of a wave with an unknown frequency traveling in soft tissue?</p> <p>A. 0.51 <math>\mu</math>s<br/>B. 0.51 m/s<br/>C. 0.51 pascals<br/>D. 0.51 watts<br/>E. 0.51 mm</p>                         | <p>25. E is the only answer with units of distance. Choice A has units of time, B has units of speed, C has units of pressure and D has units of power.</p> <p>Therefore, the only possible choice is E.</p> |
| <p>26. What is the wavelength of 2 MHz sound in soft tissue?</p> <p>A. 1.54 mm<br/>B. 0.77 mm<br/>C. 0.51 mm<br/>D. 1.54 km/s<br/>E. 3.08 mm</p>                                                                              | <p>26. B. In soft tissue, wavelength equals 1.54 mm divided by the frequency in MHz (see page 34). Thus, 2 MHz sound will have a wavelength of 0.77 mm.</p>                                                  |
| <p>27. The effects of sound waves on tissue in the body are called _____.</p>                                                                                                                                                 | <p>27. Bioeffects.</p>                                                                                                                                                                                       |
| <p>28. Which of the following are considered acoustic variables? (More than one answer may be correct.)</p> <p>A. frequency<br/>B. density<br/>C. <u>particle motion</u><br/>D. temperature<br/>E. period<br/>F. pressure</p> | <p>28. B, C, F.</p>                                                                                                                                                                                          |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Answers                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>29. Which of the following are considered acoustic parameters? (More than one answer may be correct.)</p> <ul style="list-style-type: none"> <li>A. frequency</li> <li>B. density</li> <li>C. distance</li> <li>D. pressure</li> <li>E. period</li> </ul>                                                                                                                                                                                                                                                                                                                                                            | <p>29. A, E.</p>                                                                                                                                                                                                                                                                                                                 |
| <p>30. The effects of tissue on sound waves are called _____.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <p>30. Acoustic propagation properties.</p>                                                                                                                                                                                                                                                                                      |
| <p>31. The effects of a medium on an ultrasound wave are called _____.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <p>31. Acoustic propagation properties.</p>                                                                                                                                                                                                                                                                                      |
| <p>32. How are the following parameters related—directly, inversely, or unrelated?</p> <ul style="list-style-type: none"> <li>• frequency and period</li> <li>• amplitude and power</li> <li>• amplitude and intensity</li> <li>• power and intensity</li> <li>• wavelength and intensity</li> <li>• wavelength and frequency</li> <li>• acoustic velocity and density</li> <li>• elasticity and speed of sound</li> <li>• acoustic velocity and compressibility</li> <li>• stiffness and sound speed</li> <li>• frequency and sound speed</li> <li>• frequency and intensity</li> <li>• power and frequency</li> </ul> | <p>32.</p> <ul style="list-style-type: none"> <li>• inversely</li> <li>• directly</li> <li>• directly</li> <li>• directly</li> <li>• unrelated</li> <li>• inversely</li> <li>• inversely</li> <li>• inversely</li> <li>• inversely</li> <li>• directly</li> <li>• unrelated</li> <li>• unrelated</li> <li>• unrelated</li> </ul> |

## Describing Pulsed Waves

In addition to the seven parameters that describe continuous waves (Chapter 3, *Describing Sound Waves*), five new terms and their definitions must be added to our vocabulary.

The five additional parameters in Fig. 4.1 are needed to completely describe **pulsed sound**.

At the end of your studies, this distinctive arrangement will help you organize and recall the material effectively.

**pulse duration**

**spatial pulse  
length**

**pulse repetition period**

**pulse repetition frequency**

**duty factor**

Fig. 4.1 Five parameters describe pulsed sound.

## Pulsed Ultrasound

In diagnostic ultrasound, continuous wave sound cannot create anatomic images. Rather, imaging systems produce short bursts, or **pulses**, of acoustic energy to create every picture of anatomy.

### *What is pulsed sound?*

A pulse of ultrasound is a collection of cycles that travel together. A pulse must have a beginning and an end. Although a pulse is made up of individual cycles, the entire pulse moves as a single unit.

A pulse is similar to a train. A train consists of individual cars, but travels as a single entity. Similarly, a pulse consists of individual cycles, but propagates as a single unit.

Pulsed ultrasound has **two components** (see Fig. 4.2):

- transmit, talking, or "on" time
- receive, listening, or "off" time



**Fig. 4.2** Sound pulses have an on time and an off time.



## Pulse Duration

Each particular ultrasound transducer emits a pulse with a fixed duration. The pulse duration cannot change for that transducer.

### Pulse Duration

**Pulse duration** is the **actual time** from the **start of a pulse** to the **end of that pulse**. Pulse duration is a single transmit, talking, or “on” time (see Fig. 4.3).

### Units

Pulse duration is reported in units of **time**, such as microseconds ( $\mu\text{s}$ ).

### Typical Values

The typical value of pulse duration in diagnostic ultrasound is **0.3 to 2.0  $\mu\text{s}$**  (microseconds, or millionths of a second.)

### Determined By

Pulse duration is determined by the **sound source** only, not by the medium through which the sound travels.

### Adjustable

**No.** The sonographer cannot alter pulse duration while using a particular ultrasound system and transducer.

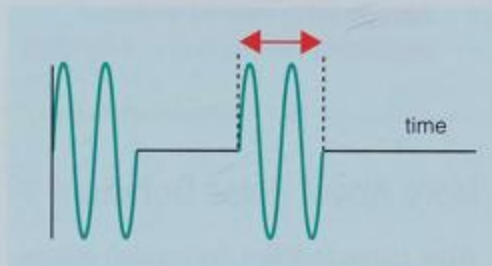


**Fig. 4.3** The pulse duration is identified by the red arrow, representing the transmit time.

Pulse duration is equal to the number of cycles in each pulse, multiplied by the period of each cycle.

$$\text{pulse duration } (\mu\text{s}) = \# \text{ cycles} \times \text{period } (\mu\text{s})$$

Pulse duration is:

- directly proportional to the number of cycles in the pulse
- directly proportional to period
- inversely proportional to frequency

$$\text{pulse duration } (\mu\text{s}) = \frac{\# \text{ cycles}}{\text{frequency (MHz)}}$$

## More About Pulse Duration

*What characteristics distinguish pulses with long duration from those with short duration? (See Fig. 4.4.)*

Two characteristics create pulses of long duration:

- many cycles in the pulse, or
- individual cycles with long periods

Two characteristics create pulses of short duration:

- few cycles in the pulse, or
- individual cycles with short periods

In clinical imaging, a pulse typically contains 2 to 4 cycles.

*Which type of pulse is more desirable in diagnostic imaging, and why?*

Shorter duration pulses are desirable for imaging because they create images of greater accuracy.

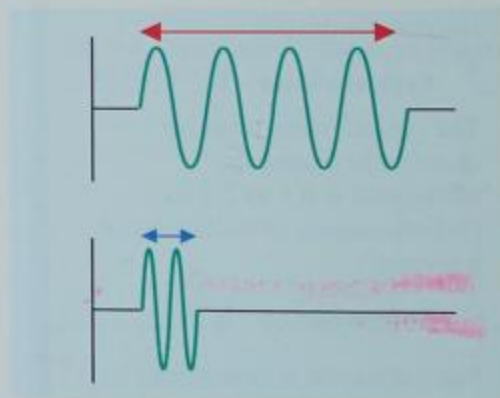


**Fig. 4.4** The long duration pulse on top has many cycles with long periods (red arrow). The short duration pulse on the bottom has fewer cycles with shorter periods (blue arrow).

## Spatial Pulse Length

Spatial pulse length is the distance from the front tip of our imaginary “train” to the end of the “caboose.”

### Spatial Pulse Length

Spatial pulse length is the **distance** that a pulse occupies in space from the start to the end of a pulse (see Fig. 4.5).

#### Units

Spatial pulse length has units of distance, such as mm.

#### Typical Values

In clinical imaging, spatial pulse length in soft tissue ranges from 0.1 to 1.0 mm.

#### Determined By

Pulse length is determined by **both the source and the medium**. It equals the number of cycles in each pulse times the wavelength of each cycle. Since wavelength is determined by both the source and medium, so is the spatial pulse length.

#### Adjustable

No. The sonographer cannot alter pulse length. In a particular medium, a transducer's pulse has a fixed length that cannot change.

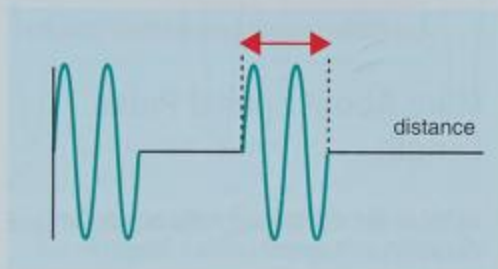


**Fig. 4.5** The spatial pulse length is identified by the red arrow. It is a distance.

$$\text{spatial pulse length (mm)} = \# \text{ cycles} \times \text{wavelength (mm)}$$

**Spatial pulse length is:**

- directly proportional to the number of cycles in the pulse
- directly proportional to wavelength
- inversely proportional to frequency

## More About Spatial Pulse Length

**What is the difference between pulse duration and spatial pulse length?**

It is important to distinguish between pulse duration and spatial pulse length. Although pulses with longer durations have longer lengths, duration and length are two different parameters:

- **Pulse duration** is the **time** that a pulse is "on" and is typically measured in microseconds ( $\mu\text{s}$ ).
- **Spatial pulse length** is the **distance** of the pulse end to end, typically measured in millimeters (mm).

Imagine our train analogy:

- The time that it takes the train to roll past us at a railroad crossing is the **pulse duration**.
- The length of the train, from the beginning of the locomotive to the end of the caboose, is the **spatial pulse length**.

**Which characteristics distinguish pulses with long pulse length from those with short length?**

Two characteristics create **long** pulses:

- many cycles in the pulse
- cycles with longer wavelengths

Two characteristics create **short** pulse length:

- fewer cycles in the pulse
- cycles with shorter wavelengths

**Which type of pulse is more desirable in diagnostic imaging, and why?**

**Pulses of shorter length are desirable** because they create more accurate images.



# Pulse Repetition Period

## Pulse Repetition Period

Pulse repetition period (PRP) is **the time from the start of one pulse to the start of the next pulse**. It includes one pulse duration plus one listening time (see Fig. 4.6).

### Units

Pulse repetition period is reported in units of time, such as ms.

### Typical Values

The typical value of pulse duration in diagnostic ultrasound is 100 microseconds ( $\mu\text{s}$ ) to 1 millisecond (ms). Pulse repetition period is generally about 100 to 1,000 times longer than pulse duration.

### Determined By

Pulse repetition period is determined by the **sound source** only, *not* by the medium through which the sound travels. Pulse repetition period is determined by the **imaging depth** that the sonographer selects.

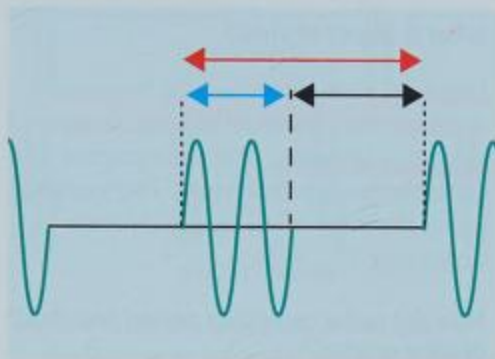


**Fig. 4.6** Pulse repetition period is identified by the red arrow. It is one transmit time (blue) plus one receive time (black).

### Adjustable

**Yes.** The sonographer can change the pulse repetition period. When the sonographer adjusts the scan's depth of view, the pulse repetition period is also altered.

- When the system is imaging at shallow depths, the time from one pulse to the next is short.
- When the system is imaging more deeply, the time from one pulse to the next is longer.

**Hint:** PRP is unrelated to period. It is related only to depth of view.

## More About Pulse Repetition Period (PRP)

### What is depth of view?

Depth of view describes the maximum distance into the body that an ultrasound system is imaging. The sonographer controls the depth of view. The markers along the edge of an image indicate depth (see Fig. 4.7).

### How are pulse repetition period and depth of view related?

Pulse repetition period and imaging depth are directly related.

- As depth of view increases, pulse repetition period increases.
- As depth of view decreases, pulse repetition period decreases.

### What are the two components of pulse repetition period? Which one can the sonographer change?

The two components of the pulse repetition period are:

- the transmit time or on time
- the receive time or off time

The transmit time is called the pulse duration. The sonographer cannot change the pulse duration because it is a characteristic of the transducer and has a fixed value.

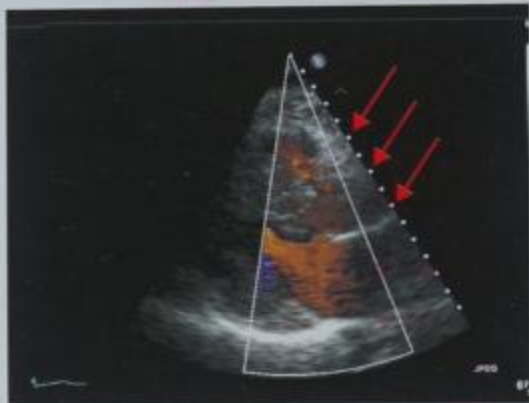


Fig. 4.7 Markers along the edge of an image, shown as small white dots (red arrows), indicate depth.

The transducer receives reflections from anatomic reflectors in the body during the receive or "listening time." The sonographer can alter the listening time when adjusting the imaging depth (see Fig. 4.8).

- With deeper imaging, the listening time and the pulse repetition period lengthen.
- With shallower imaging, the listening time and the pulse repetition period shorten.

Only the listening time portion of the pulse repetition period is changed when the sonographer alters imaging depth.

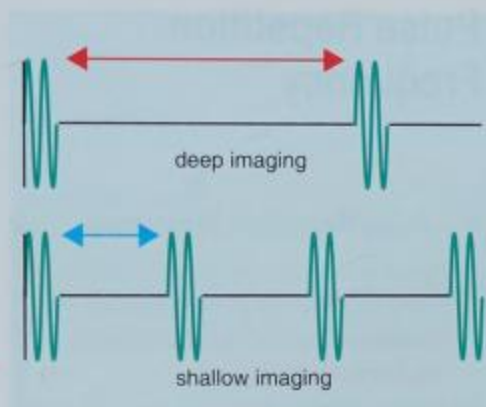


**Fig. 4.8** Listening time is longer with deep imaging (upper, red arrow) and shorter with shallow imaging (lower, blue arrow).

## Pulse Repetition Frequency

### Pulse Repetition Frequency

Pulse repetition frequency (PRF) is the number of pulses that an ultrasound system transmits into the body each second.

With regard to PRF, the number of cycles in each pulse is meaningless. We are interested only in the number of pulses created each second.

### Units

Pulse repetition frequency is reported in units of Hz (hertz), or per second.

### Typical Values

The typical value of pulse repetition frequency is 1,000 to 10,000 hertz, or one to ten thousand pulses per second.

### Determined By

Pulse repetition frequency is determined only by the sound source, not by the medium through which the sound travels.

Pulse repetition frequency is determined by the maximum imaging depth of the system.

### Adjustable

Yes. The sonographer can change pulse repetition frequency by adjusting the depth of view of a scan.

- When the system is imaging shallow, the pulse repetition frequency is higher.
- When the system is imaging deep, the pulse repetition frequency is lower.

**Hint:** PRF is unrelated to frequency. It is related only to depth of view.



## More About Pulse Repetition Frequency (PRF)

*How are pulse repetition frequency and depth of view related?*

Pulse repetition frequency and depth of view are **inversely related** (see Fig. 4.9).

- As depth of view increases, pulse repetition frequency decreases.
- As depth of view decreases, pulse repetition frequency increases.

*An ultrasound machine is imaging to a depth of 2 cm. Would the pulse repetition frequency be described as high or low?*

The pulse repetition frequency is high when systems image only to a shallow depth. When the depth of view is shallow, the system waits only a short time and then creates a new pulse. This procedure is repeated rapidly, over and over. The system continues to produce pulse after pulse; therefore, the PRF frequency is high.

*When the sonographer adjusts the depth of view to 20 cm, what happens to the pulse repetition frequency?*

The pulse repetition frequency is reduced when systems image to a greater depth. A pulse is directed into the body. However, the system waits longer before creating a new pulse. This procedure is repeated, but fewer times per second than when imaging to shallow depths.

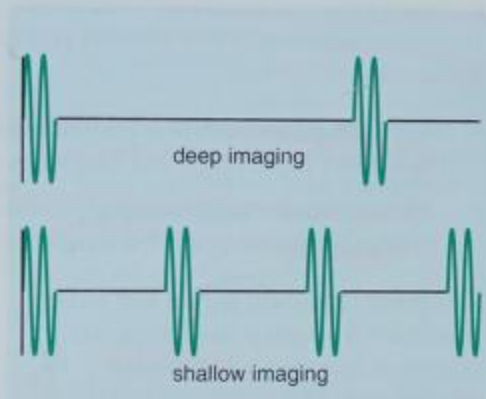


**Fig. 4.9** Deep imaging occurs with a lower pulse repetition frequency (PRF), whereas shallow imaging occurs with a higher pulse repetition frequency.

## Relationship Between Pulse Repetition Period (PRP) and Pulse Repetition Frequency (PRF)

Pulse repetition period (PRP) and pulse repetition frequency (PRF) are **inversely related** to each other.

- A longer pulse repetition period results in a lower pulse repetition frequency.
- A shorter pulse repetition period results in a higher pulse repetition frequency.

The pulse repetition period and pulse repetition frequency have a special relationship called a **reciprocal relationship**. In a reciprocal relationship, when the two parameters are multiplied together, the result is 1.

$$PRF = \frac{1}{PRP}$$

$$PRP = \frac{1}{PRF}$$

$$PRF \times PRP = 1$$

Use complementary metric units (see page 6):

- seconds (PRP) and hertz (PRF)
- millisecs (PRP) and kilohertz (PRF)

| Questions                                                                                                                                                                                       | Answers                                                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Which of these four values for pulse repetition frequency would have the longest pulse repetition period?<br>A. 2 kHz<br>B. 4,000 Hz<br>C. 6 Hz<br>D. 1 kHz                                  | 1. C. 6 Hz. Pulse repetition period is the reciprocal of pulse repetition frequency. This choice has the lowest pulse repetition frequency and, thus, the longest pulse repetition period.     |
| 2. Four pulses have pulse repetition periods as listed below. Which of the following four waves has the highest pulse repetition frequency?<br>A. 8 s<br>B. 80 ms<br>C. 5 ms<br>D. 400 ks       | 2. C. 5 ms. The pulse with the shortest pulse duration will have the highest pulse repetition frequency.                                                                                       |
| 3. Which of these four pulses with PRFs listed below has the shortest pulse repetition period?<br>A. 12 kHz<br>B. 6,000 Hz<br>C. 20 kHz<br>D. 1 kHz                                             | 3. C. 20 kHz. Pulse repetition period is the reciprocal of pulse repetition frequency. This answer has the highest pulse repetition frequency and, thus, the shortest pulse repetition period. |
| 4. Four waves have pulse repetition periods as listed below. Which of the following four waves has the lowest pulse repetition frequency?<br>A. 8 s<br>B. 80 $\mu$ s<br>C. 8000 ns<br>D. 800 ms | 4. A. 8 s. The pulse with the longest pulse duration will have the lowest pulse repetition frequency.                                                                                          |
| 5. True or False. Two waves can have identical pulse repetition frequencies, even if their pulse repetition periods are different.                                                              | 5. False. Two waves can never have identical PRFs if their pulse repetition periods are different.                                                                                             |
| 6. True or False. Two waves can have identical PRFs, even if their periods are different.                                                                                                       | 6. True. Period and pulse repetition frequency are unrelated.                                                                                                                                  |
| 7. True or False. Two waves can have identical PRFs, even if their frequencies are different.                                                                                                   | 7. True. Frequency and pulse repetition frequency are unrelated.                                                                                                                               |
| 8. True or False. PRF and pulse repetition period are determined only by the imaging depth.                                                                                                     | 8. True. This is a very important concept.                                                                                                                                                     |



## Duty Factor

### Duty Factor

Duty factor is the **percentage or fraction of time** that the system **transmits a pulse** (see Fig. 4.10).

### Units

None. Duty factor is a percentage, and is therefore dimensionless.

### Typical Values

In clinical imaging, duty factor ranges from 0.002 to 0.005, or 0.2% to 0.5%.

When creating anatomic images, duty factors are in the range of 0.2%, indicating that ultrasound systems spend a very small percentage of time transmitting and a very large percentage of time (99.8%) receiving.

The duty factor is 1.0 (100%) for continuous wave sound, because the system is always transmitting.

### Determined By

Duty factor is determined by the **sound source** only.

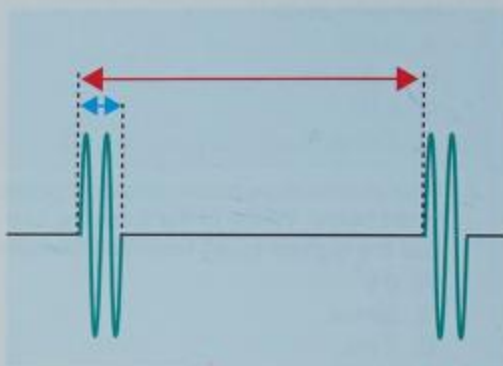


**Fig. 4.10** Duty factor is the pulse duration (blue line) divided by the pulse repetition period (red line).

### Adjustable

Yes. Changing the depth of view of a scan also changes the duty factor. Duty factor is *inversely related* to imaging depth. Duty factor is higher when the system is imaging at shallow depths, and lower when imaging at greater depths.



## More About Duty Factor

### How is duty factor calculated?

Recall that the duty factor is the fraction of time during which an ultrasound system transmits a wave.

The time required to transmit a pulse is the pulse duration. The pulse repetition period includes both one transmit time and one receive time. Duty factor can be represented mathematically as:

$$\text{duty factor (\%)} = \frac{\text{pulse duration}}{\text{pulse rep. period}} \times 100$$

### What are the maximum and minimum values for duty factor?

The maximum value for duty factor is 1, or 100%; this value is only achieved with continuous wave sound. Continuous wave sound cannot create anatomic images; therefore, duty factors for imaging systems must always be less than 100%.

The minimum value of duty factor is 0%, which exists only when the transducer is silent. With anatomic imaging, a typical value for the duty factor is 0.2%, which means that the system is listening approximately 500 times longer than it is transmitting.

### How does the sonographer change duty factor?

Duty factor changes when the sonographer alters imaging depth.

As imaging depth increases, transmit time, or pulse duration, remains constant while listening time is prolonged. As a result, the duty factor decreases with deeper imaging. Duty factor increases with shallower imaging.

The equation to the left shows that duty factor is related to both pulse duration and pulse repetition period. Pulse duration is a characteristic of each individual transducer and is not generally changed by the sonographer. However, the sonographer does alter the pulse repetition period when changing the depth of view. In particular, the listening component of the pulse repetition period lengthens as imaging depth increases.

Table 4.1 Shallow vs. Deep Imaging

| Shallow Imaging      | Deep Imaging        |
|----------------------|---------------------|
| • less listening     | • more listening    |
| • shorter PRP        | • longer PRP        |
| • higher PRF         | • lower PRF         |
| • higher duty factor | • lower duty factor |

| Questions                                                                                                                                                                                   | Answers                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| 1. If all other factors remain unchanged, what happens to the duty factor [increases, decreases, remains the same] when the pulse repetition frequency increases?                           | 1. increases                                                                                                    |
| 2. If all other factors remain unchanged, what happens to the duty factor [increases, decreases, remains the same] when imaging depth increases?                                            | 2. decreases                                                                                                    |
| 3. If all other factors remain unchanged, what happens to the duty factor [increases, decreases, remains the same] when the pulse repetition period increases?                              | 3. decreases                                                                                                    |
| 4. If all other factors remain unchanged, what happens to the duty factor [increases, decreases, remains the same] when the sonographer uses a new transducer with a longer pulse duration? | 4. increases                                                                                                    |
| 5. What is the duty factor if the pulse duration is 1 $\mu$ s and the pulse repetition period is 1 ms?<br>A. 100%<br>B. 0.1<br>C. 0.01<br>D. 0.001                                          | 5. D                                                                                                            |
| 6. Which of the following terms does not belong with the others?<br>A. high duty factor<br>B. shallow imaging<br>C. low PRF<br>D. short pulse repetition period                             | 6. C. Low PRF is associated with deep imaging. The other three choices are all associated with shallow imaging. |
| 7. Which of the following terms does not belong with the others?<br>A. low duty factor<br>B. shallow imaging<br>C. low PRF<br>D. long pulse repetition period                               | 7. B. Shallow imaging does not belong. The other three choices are all associated with deep imaging.            |

## Summary: Pulsed Sound

The five parameters that completely describe pulsed sound are found in Fig. 4.11. The arrangement serves as a learning tool. The labels explain the significance of this blueprint for learning.

**Hint:** When adjusting imaging depth, the system changes the pulse repetition period, pulse repetition frequency, and duty factor.

The pulse duration and spatial pulse length are characteristics of the pulse itself and are inherent in the design of the transducer system. They cannot be changed by the sonographer.

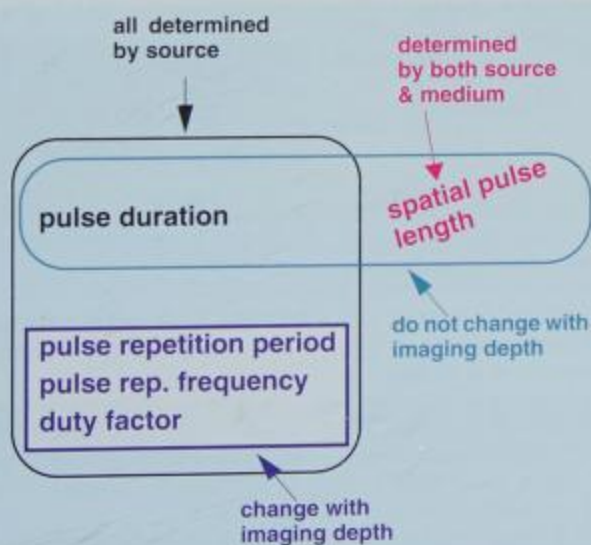


Fig. 4.11 Five parameters that describe pulsed sound waves.

## Parameters That Describe Both Pulsed and Continuous Waves

Individual cycles are the building blocks of both pulsed and continuous waves (see Fig. 4.12). The parameters that describe a single cycle can describe both pulsed and continuous wave sound.

These parameters are **period, frequency, wavelength, and propagation speed**.

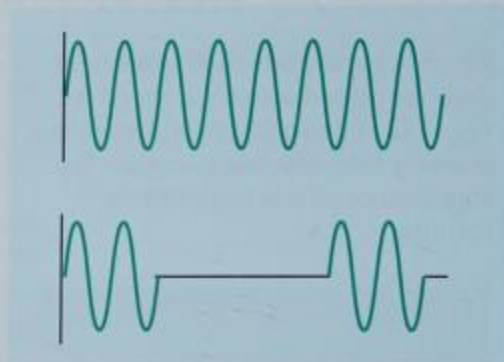


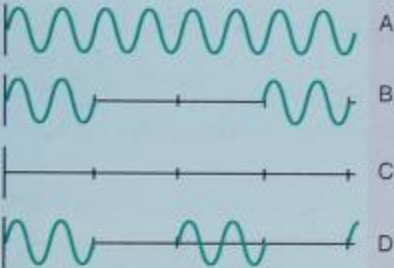
**Fig. 4.12** Continuous and pulsed wave sound of the same frequency are composed of identical cycles.

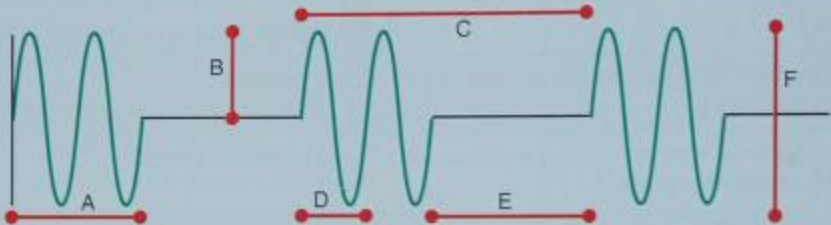
**Table 4.2** Parameters for Pulsed Waves

| Parameter                  | Adjustable | Units                  | Determined by | Typical Value            |
|----------------------------|------------|------------------------|---------------|--------------------------|
| pulse duration             | no         | $\mu\text{sec}$ , time | source        | 0.5 to 3.0 $\mu\text{s}$ |
| pulse repetition period    | yes        | msec, time             | source        | 0.1 to 1.0 ms            |
| pulse repetition frequency | yes        | Hz, per sec            | source        | 1 to 10 kHz              |
| spatial pulse length       | no         | mm, distance           | both          | 0.1 to 1.0 mm            |
| duty factor                | yes        | none                   | source        | 0.2% to 0.5%             |



# Review: Pulsed Waves

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                         |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. _____ is the time from the start of a pulse to the end of that pulse.                                                                                                                                                                                                                                                                                                                                                                                                               | 1. Pulse duration                                                                                                                                                                               |
| 2. _____ is the time from the start of a pulse to the start of the next pulse.                                                                                                                                                                                                                                                                                                                                                                                                         | 2. Pulse repetition period                                                                                                                                                                      |
|  <p>Figure 4.13 shows four wave patterns labeled A, B, C, and D. Pattern A is a continuous sine wave. Pattern B shows a pulse followed by a horizontal line (no signal) and then another pulse. Pattern C shows a horizontal line with vertical tick marks, indicating no signal. Pattern D shows a pulse followed by a horizontal line and then another pulse, with a different interval than B.</p> |                                                                                                                                                                                                 |
| Fig. 4.13 Use this graphic for the next 4 questions.                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                 |
| 3. What are the duty factors of the 4 patterns that appear in Fig. 4.13?<br><br><b>Hint:</b> To determine a duty factor, use a single pair of complete pulse duration and PRP times.                                                                                                                                                                                                                                                                                                   | 3. The duty factors are as follows: <ul style="list-style-type: none"> <li>• pattern A 100%</li> <li>• pattern B 33%</li> <li>• pattern C 0%</li> <li>• pattern D 50%</li> </ul>                |
| 4. Which of the patterns in Fig. 4.13 indicates a system with a superficial imaging depth?                                                                                                                                                                                                                                                                                                                                                                                             | 4. Choice D has the shallowest imaging depth because the pulse repetition period is the shortest.                                                                                               |
| 5. Which of the patterns in Fig. 4.13 indicates a system with a deep imaging depth?                                                                                                                                                                                                                                                                                                                                                                                                    | 5. Choice B has the deepest imaging depth because the pulse repetition period is the longest.                                                                                                   |
| 6. Which two of the patterns in Fig. 4.13 identify an ultrasound system that cannot perform anatomic imaging?                                                                                                                                                                                                                                                                                                                                                                          | 6. A and C. System A cannot perform anatomic imaging because it is continuous wave. Only pulsed sound creates imaging. Also, system C cannot perform imaging because it does not produce sound. |

| Questions                                                                                                                                                                                                                            | Answers                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                    |                                                                                                                                                                                  |
| <p><b>Fig. 4.14</b> Use these waves to answer the following 9 questions.</p>                                                                                                                                                         |                                                                                                                                                                                  |
| <p>7. Which of the following describes line A?</p> <p>A. frequency                      B. pulse rep. period<br/>C. period                          D. pulse duration<br/>E. duty factor                      F. amplitude</p>       | <p>7. D, pulse duration. If the units for line A are time, line A is a pulse duration.</p>                                                                                       |
| <p>8. Which of the following describes line A?</p> <p>A. frequency                      B. pulse rep. period<br/>C. period                          D. spatial pulse length<br/>E. duty factor                      F. amplitude</p> | <p>8. D, spatial pulse length. If the units for line A are distance, line A is a spatial pulse length.</p> <p>Both spatial pulse length and pulse duration describe a pulse.</p> |
| <p>9. Which of the following describes line B?</p> <p>A. frequency                      B. pulse rep. period<br/>C. period                          D. pulse duration<br/>E. duty factor                      F. amplitude</p>       | <p>9. F, amplitude.</p>                                                                                                                                                          |
| <p>10. Which of the following describes line C?</p> <p>A. frequency                      B. pulse rep. period<br/>C. period                          D. pulse duration<br/>E. duty factor                      F. amplitude</p>      | <p>10. B, pulse repetition period.</p>                                                                                                                                           |
| <p>11. Which of the following describes line D?</p> <p>A. frequency                      B. pulse rep. period<br/>C. period                          D. pulse duration<br/>E. duty factor                      F. amplitude</p>      | <p>11. C, period. If the units for line D are time, line D is a period.</p>                                                                                                      |
| <p>12. Which of the following describes line D?</p> <p>A. frequency                      B. pulse rep. period<br/>C. wavelength                      D. pulse duration<br/>E. duty factor                      F. amplitude</p>      | <p>12. C, wavelength. If the units for line D are distance, line D is a wavelength. Both wavelength and period describe a single cycle.</p>                                      |

| Questions                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 13. Which of the following describes line E?<br>A. frequency                      B. pulse rep. period<br>C. period                          D. pulse duration<br>E. duty factor                      F. none of the above                                                | 13. F. None of the above. Line E represents only the listening time.                                                                                                 |
| 14. Which of the following describes line F?<br>A. frequency                      B. pulse rep. period<br>C. period                          D. pulse duration<br>E. peak-to-peak amplitude                                                                               | 14. E, peak-to-peak amplitude.                                                                                                                                       |
| 15. Which of the following best describes the duty factor?<br>A. $A \times B$ B. $A/E$<br>C. $D/E$ D. $A/C$<br>E. $E \times F$ F. $(A + B)/C$                                                                                                                             | 15. D. To determine the duty factor, divide pulse duration by pulse repetition period. This is choice D.                                                             |
| 16. Pulse repetition frequency is the reciprocal of ____.                                                                                                                                                                                                                 | 16. Pulse repetition period.                                                                                                                                         |
| 17. By changing the imaging depth, which of the following does the operator also change (more than 1 may be correct)?<br>A. pulse repetition frequency<br>B. duty factor<br>C. propagation speed<br>D. pulse repetition period<br>E. amplitude<br>F. spatial pulse length | 17. A, pulse repetition frequency.<br>B, duty factor.<br>D, pulse repetition period.                                                                                 |
| 18. The speed of a 5 MHz continuous wave is 1.8 km/sec. The wave is then pulsed with a duty factor of 0.5. Calculate the new propagation speed.                                                                                                                           | 18. The propagation speed for pulsed and continuous wave sound is the same; in this case, 1.8 km/s. It depends only upon the medium through which the sound travels. |
| 19. What is the duty factor if the pulse duration is 1 microsecond, and the pulse repetition period is 1 ms?                                                                                                                                                              | 19. The duty factor is 0.001, or $10^{-3}$ .<br>$10^{-6}$ divided by $10^{-3} = 10^{-3}$ , or 0.001.                                                                 |
| 20. What is the duty factor if the pulse duration is 1 millisecond, and the pulse repetition period is 1 second?                                                                                                                                                          | 20. The duty factor is 0.001 or 0.1%,<br>0.001 divided by 1.0 = 0.001.                                                                                               |



| Questions                                                                                                                                                                                                                                                      | Answers             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 21. A sonographer adjusts the depth of view of an ultrasound scan from 8 cm to 16 cm. Would each of the following parameters increase, decrease, or remain the same?                                                                                           |                     |
| A. period                                                                                                                                                                                                                                                      | A. remains the same |
| B. frequency                                                                                                                                                                                                                                                   | B. remains the same |
| C. wavelength                                                                                                                                                                                                                                                  | C. remains the same |
| D. speed                                                                                                                                                                                                                                                       | D. remains the same |
| E. amplitude (initial)                                                                                                                                                                                                                                         | E. remains the same |
| F. pulse duration                                                                                                                                                                                                                                              | F. remains the same |
| G. PRF                                                                                                                                                                                                                                                         | G. decreases        |
| H. duty factor                                                                                                                                                                                                                                                 | H. decreases        |
| I. spatial pulse length                                                                                                                                                                                                                                        | I. remains the same |
| J. pulse repetition period                                                                                                                                                                                                                                     | J. increases        |
| 22. A sonographer is using a 3 MHz transducer and changes to a 6 MHz transducer. The imaging depth remains unchanged. Would each of the following parameters increase, decrease, or remain the same?                                                           |                     |
| A. period                                                                                                                                                                                                                                                      | A. decreases        |
| B. frequency                                                                                                                                                                                                                                                   | B. increases        |
| C. wavelength                                                                                                                                                                                                                                                  | C. decreases        |
| D. speed                                                                                                                                                                                                                                                       | D. remains the same |
| E. intensity (initial)                                                                                                                                                                                                                                         | E. remains the same |
| F. PRF                                                                                                                                                                                                                                                         | F. remains the same |
| G. pulse repetition period                                                                                                                                                                                                                                     | G. remains the same |
| 23. A sonographer is using a 3 MHz transducer and increases the output power to visualize structures that are positioned deeper in the patient. No other controls are adjusted. Would each of the following parameters increase, decrease, or remain the same? |                     |
| A. period                                                                                                                                                                                                                                                      | A. remains the same |
| B. frequency                                                                                                                                                                                                                                                   | B. remains the same |
| C. wavelength                                                                                                                                                                                                                                                  | C. remains the same |
| D. speed                                                                                                                                                                                                                                                       | D. remains the same |
| E. power (initial)                                                                                                                                                                                                                                             | E. increases        |
| F. intensity (initial)                                                                                                                                                                                                                                         | F. increases        |
| G. pulse duration                                                                                                                                                                                                                                              | G. remains the same |
| H. PRF                                                                                                                                                                                                                                                         | H. remains the same |
| I. duty factor                                                                                                                                                                                                                                                 | I. remains the same |
| J. spatial pulse length                                                                                                                                                                                                                                        | J. remains the same |
| K. pulse repetition period                                                                                                                                                                                                                                     | K. remains the same |



# Intensities

**Intensity** has previously been defined as a beam's power divided by its area. However, simply reporting a single numerical value of a beam's intensity is not always sufficient.

Intensity is reported several different ways. Five key words are related to the intensities of pulsed waves:

## Spatial

refers to distance or space. An ultrasound beam does not have the same intensity at different locations.

## Peak

the maximum value.

## Average

the mathematical middle value.

**Hint:** This material is a bit abstract. If you are studying for the boards, refer to the "10 Commandments of Intensity" on page 74. That's what you need to know!

## Temporal

PRP refers to **all time, transmit** (~~pulse duration~~) and **receive**. A pulsed ultrasound beam does not have the same intensity at different times.

## Pulsed

refers **only to the transmit time** (pulse duration). A pulsed ultrasound beam does not have the same intensity at different times during the pulse. **Pulsed** is the average intensity for the pulse duration only (ignore listening time).

## Measuring and Reporting Sound Beam Intensity

The strength of a sound beam varies, depending on the measurement point within the beam (see Fig. 5.1). In addition, intensity varies over time with pulsed ultrasound, depending on whether the system is transmitting or receiving.

Several different methods are used to describe ultrasound beam intensity. These different methods evaluate tissue exposure to sound energy, and are especially important in the study of **bioeffects**.

## Spatial Considerations

**Spatial** refers to location or space. The intensity of a sound beam varies, depending on the location of the measurement. We experience this phenomenon in everyday life when using a flashlight. When a beam of light strikes a wall, the center of the beam is brighter and has a higher intensity than the edges (see Fig. 5.2).

Uncertainty can arise when we are asked to measure the intensity of the beam. What should we report? There are two reasonable possibilities:

- The beam's intensity at the location where it is maximum. This is called the **spatial peak intensity**, or  $I_{sp}$ .
- The average intensity across the beam's entire cross-sectional area. This is called the **spatial average intensity**, or  $I_{sa}$ .



**Fig. 5.1** An ultrasound beam does not have the same intensity at different depths or at different side-to-side locations within the beam.

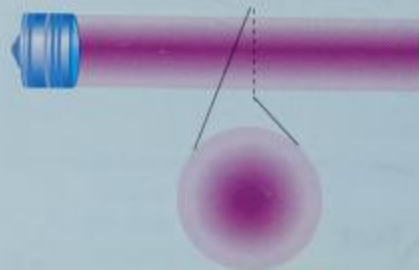


**Fig. 5.2** At a particular depth, the center of a sound beam is more intense than the edges.

**Hint:** Spatial peak intensity is always higher than the spatial average intensity.

## Temporal Considerations

The term **temporal** refers to time.

In addition to location within the beam, sound wave intensities also vary over time. With pulsed ultrasound, the transducer is usually receiving (listening), but for brief moments it is transmitting (talking).

Four different methods of measuring intensity account for the pulsing characteristics:

- Measuring the intensity of the beam at the instant in time of its maximal value is called the **temporal peak intensity**, or  $I_{tp}$  (see Fig. 5.3).
- Determining the average intensity during the most intense half-cycle is a slightly different approach to measuring peak intensity in time. This measurement is called  $I_{max}$ , or  $I_m$  (see Fig. 5.3).
- Taking the average intensity during the pulse duration—the transmit time—is called the **pulse average intensity**, or  $I_{pa}$  (see Fig. 5.4).
- Averaging the intensity during the entire pulse repetition period—both the transmit and receive times—is called the **temporal average intensity**, or  $I_{ta}$  (see Fig. 5.4).

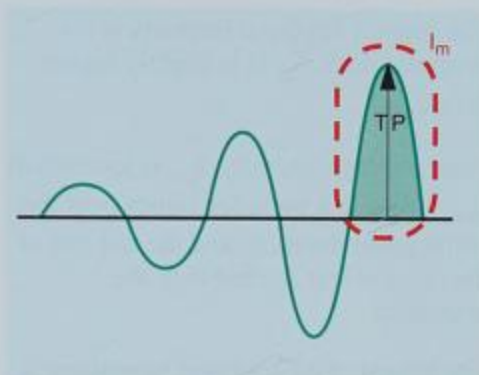


**Fig. 5.3** Peak intensities. Temporal peak intensity (arrow) is the maximum intensity.  $I_m$  (red oval) is derived from the most intense half cycle in the pulse (shaded green area).

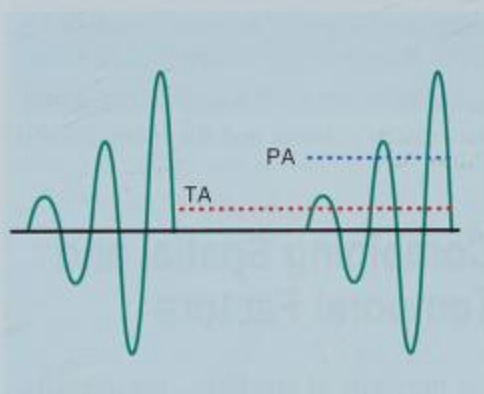


**Fig. 5.4** Average intensities. Pulse average intensity (blue line) is measured during the transmit time only. Temporal average (red line) is measured during both the transmit and receive times.



***Of the four temporal (time-related) intensity measurements, which has the highest value?***

The highest temporal intensity is the temporal peak,  $I_{tp}$ . It is slightly higher than  $I_{max}$ .

Pulse average intensity,  $I_{pa}$ , is lower than  $I_{max}$  because it includes values over the entire pulse duration, and the tail end of the pulse is less intense than the beginning.

The lowest of all temporal intensities is the temporal average,  $I_{ta}$ . Temporal average intensity is up to 500 times lower than the others because it is the only method that includes the receive time. Recall that the duty factor of pulsed ultrasound systems is approximately 0.2%; therefore,  $I_{ta}$  is very low because  $I_{ta}$  includes the 99.8% of the time when the system is silent and the intensity is 0.

**Hint:** Temporal intensities from largest to smallest:  $I_{tp}$ ,  $I_{max}$ ,  $I_{pa}$ ,  $I_{ta}$ .

## Combining Spatial and Temporal Factors

For the study of bioeffects, the intensity characteristics of sound must be described accurately with regard to both time and space. The following intensity measurements are used to describe the intensity of sound:

- $I_{sptp}$ —measured at the location where intensity is maximum, and at



the instant in time when the most powerful part of the pulse passes.

- $I_{\text{sppa}}$ —measured at the location where intensity is maximum, averaged over the transmit time (pulse duration).
- $I_{\text{spta}}$ —measured at the location where intensity is maximum and averaged over all time, both the transmit and receive times.
- $I_{\text{sata}}$ —measured over the entire cross-sectional area of the sound beam, and over all time.

## Methods for Measuring Intensity

There are six different methods to measure and report intensities. These methods describe the same wave in a variety of ways.

**Hint:** All intensities have units of  $\text{W}/\text{cm}^2$ .

**Table 5.1 Intensity Measurements**

| Intensity Measurement Methods |                                   |
|-------------------------------|-----------------------------------|
| <b>SPTP</b>                   | spatial peak, temporal peak       |
| <b>SATP</b>                   | spatial average, temporal peak    |
| <b>SPTA</b>                   | spatial peak, temporal average    |
| <b>SATA</b>                   | spatial average, temporal average |
| <b>SPPA</b>                   | spatial peak, pulse average       |
| <b>SAPA</b>                   | spatial average, pulse average    |

## The “Ten Commandments” of Intensity

**Hint:** For the boards, this is all that you really need to know!

1. Intensities may be reported in various ways with respect to time and space.
2. The different measurements of intensities are important in the study of **bioeffects**.

**SPTA** is the most relevant intensity with respect to tissue heating.

3. The units for all intensities are  $\text{watts/cm}^2$ .
4. Because peak measurements are larger than average measurements, **SPTP** intensity has the highest value, and **SATA** has the lowest value.
5. A number called the **beam uniformity coefficient** (also called **SP/SA factor**) describes the spread of a beam in space. The SP/SA factor is unitless, with a value of 1 or greater.
6. The **duty factor** describes the relationship of beam intensities with time. The duty factor is a unitless number with a value between 0 and 1.
7. For continuous wave ultrasound, the beam is always “on” and the pulse average and temporal average intensities are the same. Thus, **SPTA** = **SPPA** and **SATA** = **SAPA**.

8. When pulsed and continuous wave sound beams have the same **SPTP** intensities, the continuous wave beam has the higher **SPTA** intensity.

When pulsed and continuous wave sound beams have the same **SATP** intensities, the continuous wave beam has the higher **SATA** intensity.

9. Temporal considerations:
  - Temporal peak intensity ( $I_{tp}$ ) is maximum intensity in time.
  - $I_m$  intensity is averaged over the most intense half-cycle.
  - Pulse average intensity ( $I_{pa}$ ) is averaged only during the pulse duration (“on” time only).
  - Temporal average intensity ( $I_{ta}$ ) is averaged during the PRP (both the “on” and “off” times).
10. Spatial considerations:
  - Spatial peak intensity ( $I_{sp}$ ) is the maximum in space.
  - Spatial average intensity, ( $I_{sa}$ ) is averaged over the cross-sectional area of the beam.

**Hint:** The rank of intensities from largest to smallest is:

**SPTP** →  $I_m$  → **SPPA** → **SPTA** → **SATA**

# Interaction of Sound and Media

Sound exhibits specific behavior as it travels in different media, including soft tissue.

As sound waves propagate in the body, they move from one medium into another. For example, a pulse of sound may travel from heart muscle into the blood that fills the heart chambers.

Fortunately, weak reflections are often created as sound strikes a boundary between two different media. These reflections are the basis for the images that are created as we scan.

The remainder of the sound wave continues to penetrate deeper into the body until the next boundary is encountered. Then, at that point, another weak reflection is created.

Unfortunately, sound continues to weaken as it propagates. The ultrasound transducer and system must be sensitive enough to receive and process these weak reflections into an image.

As sound waves propagate, they may also change direction.

## Comparing Signals

Sounds waves weaken, or **attenuate** as they travel in the body. After a transducer receives a sound wave during reception, the sound wave is converted into an electrical signal. The signal is sent to the ultrasound system where it is strengthened or **amplified**. In diagnostic ultrasound, we are often interested in the degree of attenuation or the extent of amplification.

A standard measurement tool called **decibel notation** is used to report changes such as this. Decibels are based on a mathematical construct called **logarithms**. We will first discuss logarithms, then decibels.



## Logarithms

The **logarithm** is a novel method of rating numbers. Specifically, the logarithm, or **log**, of a number represents the number of 10s that are multiplied to create the original number. For example, to obtain the number 100, we multiply  $10 \times 10$ . Two tens multiplied together equals 100. Therefore, the log of 100 is 2.

The significance of a logarithmic scale is that as the logarithm increases by 1, the actual number increases tenfold. A logarithmic increase of 2 indicates that the signal is 100 times larger (recall that a "logarithm of 2" means " $10 \times 10$ ").

### *What is an everyday example of a logarithmic scale?*

The Richter scale, which measures the strength of earthquakes, is logarithmic. The significance of this scale is apparent when we compare two earthquakes; one is measured on the Richter scale as a magnitude 5 and the other as a magnitude 7. To the uninitiated, the difference would simply be  $7 - 5$ , or 2 points.

What does this 2-point difference mean? Because the Richter scale is logarithmic, each unit increase indicates that the strength of the earthquake is increased tenfold. The difference between a 7 and a 5 indicates that the larger earthquake is 100 times stronger than the smaller one!

### Examples:

#### **What is the log of 1,000?**

We multiply 10 by itself 3 times to create the number 1,000, so the log of 1,000 is 3.

#### **What is the log of 10,000?**

We multiply 10 by itself 4 times to create the number 10,000, so the log of 10,000 is 4.

**Note:** A simple way to determine the logarithm of an even power of ten (such as 10 or 10,000 or 1,000,000) is to count zeroes. There are six zeroes in a million, so the log of a million is 6. Careful, this technique only works for even powers of ten, such as 10, 100, 1000, ...



## Decibels (dB)

In diagnostic ultrasound, it is important to quantify the strength of sound beams as they are created and travel through the body. In addition, electrical signal strength and the brightness of images need to be quantified. The **decibel (dB)** is a common unit for measuring these signals.

Decibel notation is **logarithmic**.

Decibel notation does not measure absolute numbers; rather, decibels report **relative changes**. For example, relative changes include “the signal strength has doubled” or “the signal is now one-tenth as large as it used to be.”

Decibels require **two intensities**. The two intensities are the reference (or starting level) and the actual level at the time of measurement. Decibels are a **ratio**; the measured level is divided by the starting level.

**Hint:** Decibel notation is:

- a relative measurement
- a comparison
- a ratio
- logarithmic

## Positive Decibels

Positive decibels report signals that are **increasing in strength**, or **getting larger**. It is important to know the mathematical meaning of two relative changes:

- When a wave's intensity doubles, the relative change is +3 dB.
- When intensity increases ten-fold, the relative change is +10 dB.

## Negative Decibels

Negative decibels describe signals that are **decreasing** in strength, or **getting smaller**. It is important to know the mathematical meaning of two relative changes:

- When the intensity is reduced to  $\frac{1}{2}$  its original value, the relative change is -3 dB.
- When the intensity is reduced to  $\frac{1}{10}$  its original value, the relative change is -10 dB.

### Examples

A sound beam has increased from its initial intensity by a factor of 100. How is this described in decibel notation?

We know that:

$$100 = 10 \times 10$$

10 times in decibel notation is +10 dB.

Therefore, the decibel notation used for 100 is:

$$= +10 \text{ dB and another } +10 \text{ dB}$$

$$= +20 \text{ dB.}$$

A sound beam has decreased to  $\frac{1}{100}$  of its initial intensity. How is this described in decibel notation?

We know that:

$$1/100 = 1/10 \times 1/10$$

$1/10$  in decibel notation is -10 dB.

Therefore, the decibel notation used for  $1/100$  is:

$$= -10 \text{ dB and another } -10 \text{ dB}$$

$$= -20 \text{ dB.}$$

Table 6.1 Decibels and Intensities

| Decibels | Meaning          |
|----------|------------------|
| 3 dB     | double           |
| 10 dB    | ten times larger |
| - 3 dB   | half             |
| - 10 dB  | one-tenth        |

### Examples

What is the meaning of a 6 dB change?

3 dB means 2 times bigger.

6 dB is 3 dB and 3 dB.

Therefore, 6 dB means  $2 \times 2$ , or 4 times bigger.

What is the meaning of 20 dB?

10 dB means 10 times bigger.

20 dB is 10 dB and 10 dB.

Therefore, 20 dB means  $10 \times 10$ , or 100 times bigger.





## Attenuation

Sound waves weaken as they propagate in a medium. This decrease in intensity, power, and amplitude as sound travels is called **attenuation** (see Fig. 6.1 and Fig. 6.2).

Attenuation is determined by two factors:

- path length
- frequency of sound

First, the distance that the sound travels directly affects attenuation. The farther sound travels, the greater the attenuation and the weaker the beam becomes.

**Distance and attenuation are directly related.**

Second, attenuation in soft tissue depends upon the wave's frequency. Attenuation is greater in higher frequency sound than in lower frequency sound. **Frequency and attenuation are directly related.**

Attenuation is measured in decibels and reported as a relative change, not as an absolute change.

For example, when a wave propagates and its intensity is reduced to 1/10th of its original level, we say that the wave has attenuated 10 dB.

**Table 6.2 Attenuation**

| More Attenuation     | Less Attenuation    |
|----------------------|---------------------|
| • longer distances   | • shorter distances |
| • higher frequencies | • lower frequencies |



**Fig. 6.1** Attenuation of a pulse as it propagates. The pulse weakens. Its speed remains unchanged.

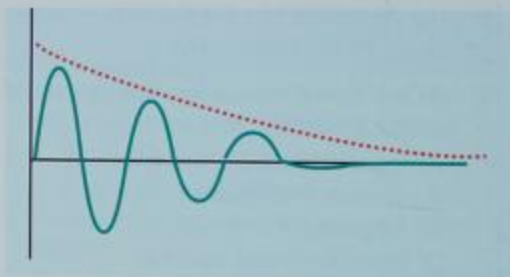


**Fig. 6.2** Attenuation. The strength of a sound beam diminishes as sound travels.

**Note:** When reporting attenuation in dB, authors will often omit the negative sign. For example, they will simply state "10 dB of attenuation." Because attenuation means a weakening or a decrease, the dBs must be negative. The meaning is -10dB.



Three processes contribute to attenuation:

1. reflection
2. scattering
3. absorption

## 1. Reflection

As sound strikes a boundary, a portion of the wave's energy may be redirected, or **reflected**, back to the sound source (see Fig. 6.3). Reflection weakens the portion of the sound wave that continues in the forward direction.

Reflection is likely to occur when the dimension of the boundary is large; that is, more than a few wavelengths of the sound.

Two forms of reflection, **specular** and **diffuse**, are created in soft tissue. Which form occurs depends on the nature of the interface that a sound wave strikes.

### Specular Reflection

When the boundary is smooth, the sound is reflected in only one direction in an organized manner. This reflection is called **specular**. Specular reflection occurs when a light wave strikes a mirror. One limitation of specular reflectors is that once the wave is slightly off-axis, the reflection does not return to the transducer. Think of specular reflection created by a mirror; if you are positioned at only a slight angle to the mirror, you no longer see your reflection (see Fig. 6.4).

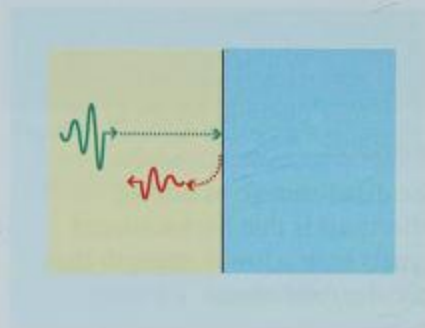


Fig. 6.3 Reflection.

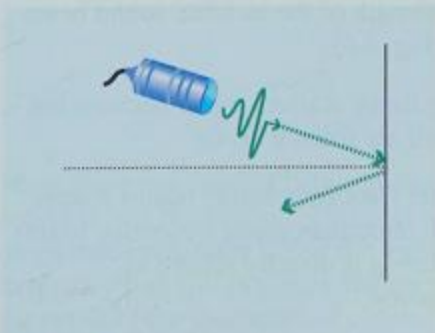


Fig. 6.4 Specular reflections at an angle do not return to the transducer.

## Diffuse Reflection

Most interfaces in the body are not smooth, but have some irregularities. When a wave reflects off an irregular surface, it radiates in more than one direction. This form of reflection is called **diffuse reflection**, or **backscatter** (see Fig. 6.5).

- An advantage of diffuse reflections is that interfaces at suboptimal angles to the sound beam can still produce reflections that will return to the transducer.
- The disadvantage of diffuse reflections is that backscattered signals have a lower strength than specular reflections.

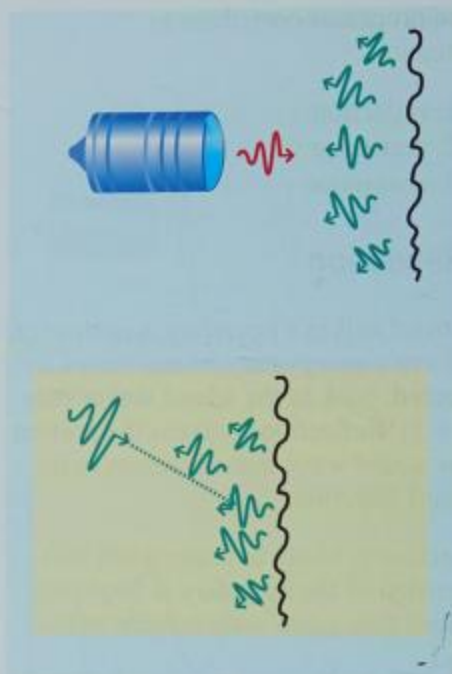


Fig. 6.5 Diffuse reflectors create backscatter.

## 2. Scattering

**Scattering** of ultrasound is the random redirection of sound in **many directions**. Sound scatters when the tissue interface is small; that is, equal to or less than the wavelength of the incident sound beam (see Fig. 6.6).

Lung tissue scatters sound because the alveoli are filled with air.

Higher frequency sound beams scatter much more than lower frequency beams. Scattering is directly related to frequency.

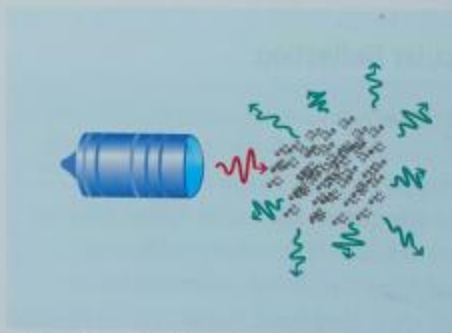


Fig. 6.6 Scattering is disorganized and chaotic.

## Rayleigh Scattering

**Rayleigh scattering** is a special form of scattering that occurs when the structure's dimensions are much smaller than the beam's wavelength. Rayleigh scattering redirects the sound wave equally in all directions. In clinical imaging, the interaction of ultrasound and red blood cells results in Rayleigh scattering (see Fig. 6.7).

Rayleigh scattering increases dramatically with increasing frequency. Mathematically, scattering is related to frequency raised to the fourth power:

$$\text{Rayleigh scattering} \propto \text{frequency}^4$$

When frequency doubles, Rayleigh scattering is 16 times greater ( $2 \times 2 \times 2 \times 2 = 16$ ).



**Fig. 6.7** Rayleigh scattering is organized and omnidirectional. Omnidirectional means "in all directions."

**Table 6.3** Interaction

|                                 | Organized           | Disorganized           |
|---------------------------------|---------------------|------------------------|
| <b>Sound back to transducer</b> | specular            | diffuse or backscatter |
| <b>Sound in all directions</b>  | Rayleigh scattering | scattering             |

## Summary: Reflection and Scattering

### *What is the significance of attenuation in diagnostic sonography?*

Recall that higher frequency sound waves produce shorter pulses, which usually create more accurate images. However, higher frequency sound attenuates more and is less capable of traveling to substantial depths.

Thus, there is a conflict between image accuracy and attenuation. The goal in diagnostic imaging is to use the highest frequency that still provides images to the depth of the structures of clinical interest.



### 3. Absorption

The third, and most sizeable component of attenuation is absorption. Absorption occurs when ultrasonic energy is converted into another energy form, such as heat. Like scattering, absorption is directly related to frequency. As a result of absorption, higher frequency waves attenuate more than lower frequency waves (see Fig. 6.8).

Sound traveling in bone undergoes extensive absorption.

### Attenuation Coefficient

Attenuation is a process whereby sound energy is extracted from a wave by absorption, scattering, and reflection. Total attenuation depends upon the frequency of the sound, the distance the beam travels, and the tissue through which the sound wave travels. It can be difficult to compare the amount of attenuation under different circumstances. A term that has simplified the reporting of attenuation is the **attenuation coefficient**.

#### Attenuation coefficient

Attenuation coefficient is the number of decibels of attenuation that occurs when sound travels one centimeter.

#### Units

The units of attenuation coefficient are **dB/cm**, decibels per centimeter.



**Fig. 6.8** Higher frequency sound (image A) undergoes more attenuation and has less penetration than lower frequency sound (image B).

The advantage of describing sound weakening with an attenuation coefficient is that its value remains constant, regardless of how far the sound travels.

In other words, if the attenuation coefficient of a sound wave traveling in a specific tissue is 2 dB/cm, that “per centimeter” value will remain constant regardless of the distance that the wave actually travels.



For example, when sound travels to a depth of 5 cm, the attenuation coefficient remains 2 dB/cm and the total attenuation of the beam is 10 dB (5 cm x 2 dB/cm).

At a depth of 10 cm, the attenuation coefficient is still 2 dB/cm, whereas the total attenuation increases to 20 dB (10 cm x 2 dB/cm).

When the attenuation coefficient is known, it is straightforward to determine the total attenuation of a sound wave as it travels. Simply **multiply** the attenuation coefficient by the distance that the sound wave traveled.

$$\text{total attenuation (dB)} = \text{atten. coefficient (dB/cm)} \times \text{distance (cm)}$$

## Attenuation Coefficient in Soft Tissue

In soft tissue, the attenuation coefficient (dB/cm) and the frequency (MHz) are directly related. Specifically, **the attenuation coefficient is one-half the frequency**.

$$\text{atten. coef. (dB/cm)} = \frac{\text{frequency (MHz)}}{2}$$

This relationship is not surprising since we know that scattering and absorption are directly related to frequency. That is, as frequency increases, scattering and absorption increase.

$$\text{atten. coef.} = 0.5 \text{ dB/cm/MHz}$$

The equations to the right apply to sound waves propagating in **soft tissue**.

These mathematical equations illustrate what is already known; for each centimeter that sound travels, more energy is lost from high frequency sound than from low frequency sound.

## Attenuation in Media Other than Soft Tissue

Thus far, we have limited our discussion of attenuation in soft tissue or “typical” biologic medium. The kidney, liver, and brain are examples of soft tissue.

Compared to soft tissue, **air** has extremely high attenuation rates. Sound with frequencies above 1 MHz attenuates entirely. The principal mechanism of attenuation in air is absorption.

Similarly, sound waves in **lung** attenuate dramatically because of scattering and absorption.

**Bone** absorbs ultrasound energy to a large extent, which results in substantial attenuation.

**Biologic fluids**, which include blood, urine, and amniotic fluid, all attenuate sound. This attenuation, however, is far less than that found in soft tissue.

Finally, no noticeable attenuation of ultrasound with frequencies less than 10 MHz is observed in **water**.

Attenuation in **muscle** is especially interesting. The attenuating properties vary, depending upon whether the sound waves are traveling along or across the muscle fibers. Sound attenuates twice as much when traveling across the fibers as when traveling along the length of the fibers.

Table 6.4 Attenuation of Ultrasound in Media

| Medium                        | Attenuation    |
|-------------------------------|----------------|
| water                         | extremely low  |
| blood, urine, biologic fluids | low            |
| fat                           | low            |
| soft tissue                   | intermediate   |
| muscle                        | higher         |
| bone and lung                 | even higher    |
| air                           | extremely high |

## Half-Value Layer Thickness

Another term that helps simplify the discussion of attenuation is **half-value layer thickness**.

### Half-value layer thickness

The half-value layer thickness is the distance sound travels in a tissue that reduces the intensity of sound to one-half its original value.

The half-value layer may also be described as the depth of tissue that results in 3 dB of attenuation to the intensity.

### Units

The units of half-value layer are **centimeters**, or any other unit of length.

### Typical Values

In clinical imaging, half-value layer ranges from 0.25 to 1.0 cm.

### Synonyms

Half-value layer is known by other names, including **penetration depth**, **depth of penetration**, and **half-boundary layer**.

The half-value layer is thin for tissues that attenuate sound a great deal, such as lung or bone. Higher frequency sound also results in a thin half-value layer.

The half-value layer is thicker for tissues that attenuate sound just a little, such as fluids. Lower frequency sound also results in a thick half-value layer.

*inversely  
Related*

Table 6.5 Half Value Layer

| Thin Half Value                                                                    | Thick Half Value                                                                  |
|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>high frequency sound</li> </ul>             | <ul style="list-style-type: none"> <li>low frequency sound</li> </ul>             |
| <ul style="list-style-type: none"> <li>media with high attenuation rate</li> </ul> | <ul style="list-style-type: none"> <li>media with low attenuation rate</li> </ul> |

The half-value layer thickness depends on two factors:

- the medium
- the frequency of sound



## Reflection and Transmission

The reflection produced as sound moves from one medium to another forms the basis for ultrasonic imaging (see Fig. 6.9). In addition, **transmission** is critical to ultrasound's ability to image structures located deep in the body. The **acoustic impedance** is an important tissue property that influences the amount of reflection.

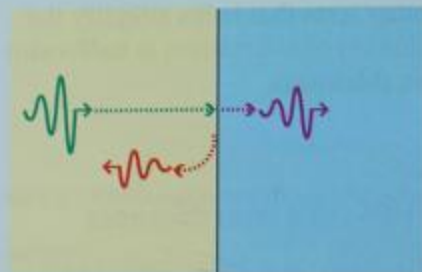


Fig. 6.9 The bases for ultrasonic imaging are reflection (red) and transmission (purple).

## Impedance

### Impedance

Impedance is the acoustic resistance to sound traveling in a medium. Acoustic impedance is calculated by multiplying the **density** of a medium by the **speed** at which sound travels in the medium.

Impedance is a calculated number associated with a medium through which sound travels. Reflection of an ultrasound wave depends upon the difference in acoustic impedances of the two media at a boundary.

**Note:** A tissue's impedance is calculated, not measured.

### Units

Impedance is reported in units of **rayls**. Impedance is often represented by the letter **Z**.

### Typical Values

In biologic media, typical values for impedance range from 1,250,000 to 1,750,000 rayls (1.25 to 1.75 Mrayls).

### Determined By

Impedance is associated with the medium only. It is calculated, not measured.

### Synonyms

Acoustic impedance is also called **characteristic impedance**.

$$\text{impedance (rayls)} = \text{density (kg/m}^3\text{)} \times \text{prop. speed (m/s)}$$



## Review: Attenuation, Half-Value Layer, and Impedance

| Questions                                                                                                                            | Answers                                                                                                                           |
|--------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| 1. Name the three components of attenuation.                                                                                         | 1. absorption, reflection, and scattering                                                                                         |
| 2. As the path length increases, the attenuation of ultrasound in soft tissue _____.                                                 | 2. increases                                                                                                                      |
| 3. Attenuation in lung tissue is [less than, greater than, the same as] attenuation in soft tissue.                                  | 3. greater than                                                                                                                   |
| 4. Attenuation in bone is _____ attenuation in soft tissue.                                                                          | 4. greater than                                                                                                                   |
| 5. Attenuation in air is _____ attenuation in soft tissue.                                                                           | 5. greater than                                                                                                                   |
| 6. What are the units of attenuation?                                                                                                | 6. Decibels (dB)                                                                                                                  |
| 7. T or F. In a given medium, attenuation is unrelated to the speed of sound.                                                        | 7. True. Attenuation and propagation speed are unrelated.                                                                         |
| 8. What is the relationship between ultrasound frequency and the attenuation coefficient in soft tissue?                             | 8. In soft tissue, the attenuation coefficient in dB per centimeter is approximately one half of the ultrasonic frequency in MHz. |
| 9. What are the units of the half-value layer thickness?                                                                             | 9. distance: centimeters                                                                                                          |
| 10. As frequency decreases, depth of penetration _____.                                                                              | 10. increases                                                                                                                     |
| 11. As path length increases, the half boundary layer _____.                                                                         | 11. remains the same                                                                                                              |
| 12. Impedance is associated with _____.                                                                                              | 12. only the medium                                                                                                               |
| 13. As the path length increases, the attenuation coefficient of ultrasound in soft tissue [decreases, remains the same, increases]. | 13. remains the same                                                                                                              |
| 14. Acoustic impedance = _____ x _____.                                                                                              | 14. impedance =<br>density ( $\text{kg/m}^3$ ) x propagation speed (m/s)                                                          |

| Questions                                                                                                                                                     | Answers                                                                                                                                                                                                                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 15. Two media A and B have the same densities. The speed of sound in medium A is 10% higher than in medium B. Which medium has the higher acoustic impedance? | 15. Medium A's acoustic impedance is higher than medium B's. Recall that impedance equals speed multiplied by density. Since both media have identical densities and medium A's speed is 10% higher, then medium A's impedance is 10% higher.                                              |
| 16. Impedance is important in _____ at boundaries.                                                                                                            | 16. reflections                                                                                                                                                                                                                                                                            |
| 17. Which is better to use while examining a carotid artery, a 7.5 or 3.0 MHz transducer?                                                                     | 17. The carotid artery is a superficial structure. A 7.5 MHz transducer is better because the higher frequency transducer produces the better image. We can use the higher frequency transducer in this example because the structure is superficial and attenuation is of little concern. |

## Incidence

A sound pulse strikes many tissue interfaces as it travels in the body. The angle at which the wave strikes the boundary determines the behavior of the pulse.

## Angles

There are three types of angles:

**Acute**—less than  $90^\circ$

**Right**—exactly  $90^\circ$

**Obtuse**—greater than  $90^\circ$

Angles with a measure other than  $90^\circ$  are also called **oblique** angles:

- acute angles are oblique
- obtuse angles are oblique

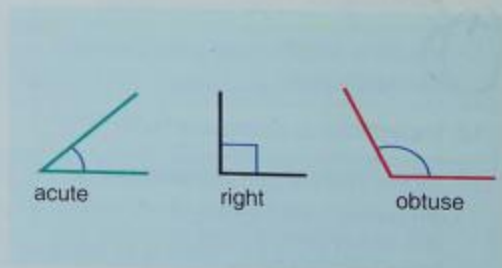


**Fig. 6.10** Green, acute angle. Black, right angle. Red, obtuse angle.

## Normal Incidence

### Normal incidence

Normal incidence means that the incident sound beam strikes the boundary at **exactly 90 degrees**.

### Typical Values

For incidence to be normal, the angle must equal 90 degrees.

### Synonyms

Normal incidence is also called:

- perpendicular
- orthogonal
- right angle
- 90 degrees

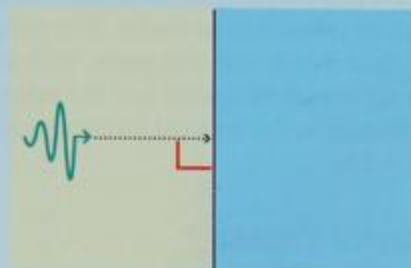


Fig. 6.11 Sound striking a boundary at normal incidence.

## Oblique Incidence

### Oblique incidence

Oblique incidence occurs when the incident sound beam strikes the boundary at any angle **other than 90°**.

### Typical Values

For incidence to be oblique, the angle must **not** equal 90 degrees.

### Synonyms

Oblique means not at right angles or non-perpendicular.

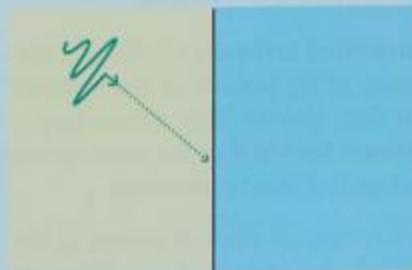


Fig. 6.12 Sound striking a boundary with oblique incidence.

## Incident, Reflected, and Transmitted Sound

A sound wave propagating through the body will eventually strike a boundary between two different media. The pulse may then divide into two parts, with one part redirected backward and the other continuing in the forward direction (see Fig. 6.13).

### Incident Intensity

**Incident intensity** (green) is the sound wave's intensity immediately *before* it strikes a boundary.

### Reflected Intensity

**Reflected intensity** (red) is the intensity of the portion of the incident sound beam that, *after* striking a boundary, **returns back** from where it came.

### Transmitted Intensity

**Transmitted intensity** (purple) is the intensity of the portion of the incident beam that, *after* striking a boundary, **continues forward** in the same general direction that it was traveling.

There is conservation of energy at the boundary. As a result, the incident intensity equals the reflected plus the transmitted intensities.

incident (starting) intensity = reflected intensity + transmitted intensity

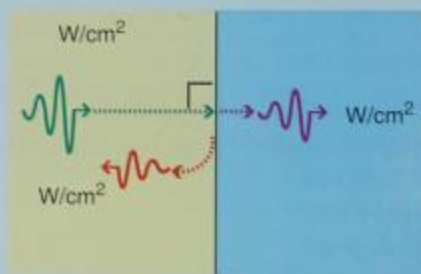


**Fig. 6.13** Incident—green, reflected—red, and transmitted—purple intensities. All intensities have units of  $\text{W}/\text{cm}^2$ .

**Hint:** All intensities have units of  $\text{W}/\text{cm}^2$ .



## Intensity Reflection Coefficient (IRC)

The **intensity reflection coefficient (IRC)** is the **percentage** of the intensity that bounces back when a sound beam strikes the boundary between two media (see Fig. 6.14).

In clinical imaging, very little (1% or less) of a sound wave's intensity is reflected at a boundary between two soft tissues.

A greater percentage of the wave is reflected when sound strikes a boundary such as between soft tissue and bone, or between soft tissue and air.

## Intensity Transmission Coefficient (ITC)

The **intensity transmission coefficient (ITC)** is the **percentage** of intensity that passes in the forward direction when the beam strikes an interface between two media. (see Fig. 6.14).

In clinical imaging, most (99% or more) of a sound wave's intensity is transmitted at a boundary between two soft tissues.

A smaller percentage of the wave is transmitted when sound strikes a boundary between bone and soft tissue.

The coefficients IRC and ITC are both reported as **percentages**, and are dimensionless.

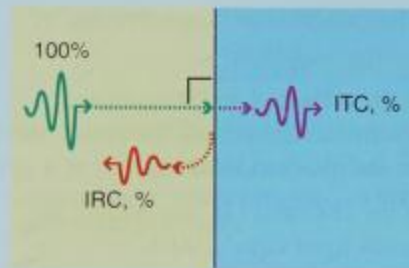


**Fig. 6.14** Intensity reflection and intensity transmission coefficients are percentages.

As a sound beam strikes a boundary, *energy is conserved*, and 100% of the intensity must be accounted for. The following relationship applies:

$$100\% = \text{inten. reflection coef. (IRC) (\%)} + \text{intensity trans. coef. (ITC) (\%)}$$

## Summary and Review

At the boundary between two media:

- The principle of “conservation of energy” applies.
- If the reflected and transmitted intensities are added, the result must be the incident intensity.
- If the IRC and ITC are added, the result must equal 100%.

**Notes:** Intensities are reported with units of  $\text{W}/\text{cm}^2$ .

Coefficients are reported as percentages, without units.

| Questions                                                                                                                                                                                                                                                                                                                                                                              | Answers                                                                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| <p>1. A sound wave with an intensity of <math>50 \text{ W}/\text{cm}^2</math> strikes a boundary and is totally reflected. What is the intensity reflection coefficient?</p> <p>A. <math>50 \text{ w}/\text{cm}^2</math><br/>           B. <math>25 \text{ w}/\text{cm}^2</math><br/>           C. <math>0 \text{ w}/\text{cm}^2</math><br/>           D. 100%<br/>           E. 0</p> | <p>1. D. Since the wave is totally reflected, the intensity reflection <b>coefficient</b> is 100%.</p>       |
| <p>2. A sound wave with an intensity of <math>50 \text{ W}/\text{cm}^2</math> strikes a boundary and is totally reflected. What is the reflected intensity?</p> <p>A. <math>50 \text{ w}/\text{cm}^2</math><br/>           B. <math>25 \text{ w}/\text{cm}^2</math><br/>           C. <math>0 \text{ w}/\text{cm}^2</math><br/>           D. 100%<br/>           E. 0</p>              | <p>2. A. Since the wave is totally reflected, <b>intensity</b> is <math>50 \text{ w}/\text{cm}^2</math>.</p> |

## Reflection with Normal Incidence

When a sound beam strikes a tissue boundary at a  $90^\circ$  angle (**normal incidence**), reflection occurs only if the media on either side of the boundary have **different impedances** (see Fig. 6.15).

The percentage of the incident beam that is reflected is related to the difference in the impedances of the tissues:

- No reflection will occur if the two media have identical impedances.
- A small reflection will occur if the impedances are slightly different.
- A large reflection will occur if the impedances are substantially different.

Recall that the intensity reflection coefficient is the percentage of intensity bounced back when the beam passes from one medium to another. With normal incidence, use the equation on the right to calculate the coefficient:

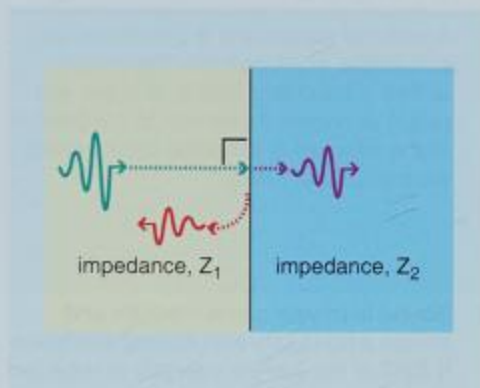


**Fig. 6.15** With normal incidence, reflection depends upon different impedances in the yellow and blue media.

$$\text{IRC (\%)} = \left[ \frac{Z_2 - Z_1}{Z_2 + Z_1} \right]^2 \times 100$$



## Review

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. A pulse of ultrasound is propagating in soft tissue, such as liver. The pulse strikes a boundary with a different soft tissue at normal incidence. What portion of the intensity is reflected back toward the transducer? Why?                                                                                                                                                                                                    | 1. A very small percentage of sound, typically less than 1%, is reflected at a boundary between two soft tissues. The impedances of two soft tissues are similar, and the difference in impedance directly determines the intensity reflection coefficient. Very little reflection occurs when the impedances have similar, but not identical, values.               |
| 2. Sound is traveling in a medium and strikes a boundary with normal incidence. If 63% of the wave's intensity is reflected back toward the transducer, what percentage is transmitted?                                                                                                                                                                                                                                              | 2. 37% of the intensity will be transmitted. Conservation of energy occurs at a boundary, and as a result, the sum of the reflected and transmitted intensities must equal 100%. $63\% + 37\% = 100\%$ .                                                                                                                                                             |
| 3. A pulse of ultrasound is propagating in bone and strikes an interface with soft tissue at $90^\circ$ . A giant reflection is created. <ul style="list-style-type: none"> <li>• From these facts alone, what can be said about the impedance of bone?</li> <li>• What can be said about the impedance of soft tissue?</li> <li>• What can be said about the differences between the impedances of bone and soft tissue?</li> </ul> | 3. Nothing can be stated about the impedance of bone or soft tissue based on the information given.<br><br>However, because a large reflection was created, the impedances of these two media must be dissimilar. Reflections with normal incidence are created based on the <i>difference</i> in the impedances, not on the <i>actual values</i> of the impedances. |
| 4. Sound strikes a boundary between two media orthogonally. Although the media are very different, no reflection is created. How can this be?                                                                                                                                                                                                                                                                                        | 4. With normal incidence, reflections occur only when the impedances of the two media at the interface are different. Two different media can have the same impedances, and when that happens, no reflection will be created.                                                                                                                                        |
| 5. Which of the following terms does not belong with the others? <ul style="list-style-type: none"> <li>A. orthogonal</li> <li>B. oblique</li> <li>C. normal</li> <li>D. perpendicular</li> </ul>                                                                                                                                                                                                                                    | 5. B. Oblique means "other than 90 degrees."<br><br>The other three terms all have a meaning of "equal to 90 degrees."                                                                                                                                                                                                                                               |



## Transmission with Normal Incidence

The **intensity transmission coefficient (ITC)** is the percentage of the intensity that continues to move forward when the beam reaches a boundary between two media. With normal incidence, *all* of the sound is transmitted when the two media have the same impedance.

The value of the ITC ranges from 0% to 100% and is defined by the following equations:

$$\begin{aligned} \text{ITC (\%)} &= \frac{\text{transmitted intensity}}{\text{incident intensity}} \times 100 \\ &= 1 - \text{intensity reflection coefficient} \end{aligned}$$

Given what we have just learned about reflection, it is relatively simple to evaluate the percentage of transmitted sound. Since 100% of a beam's intensity must be accounted for, the percentage of the reflected sound must be subtracted from 100%. Whatever percentage remains must be the intensity transmission coefficient. In other words, there is **conservation of energy** at the boundary (see Fig. 6.16).

In clinical ultrasonic imaging, 1% or less of the incident sound beam is reflected at a soft tissue–soft tissue boundary. Thus, over 99% of the intensity is transmitted at this type of boundary.

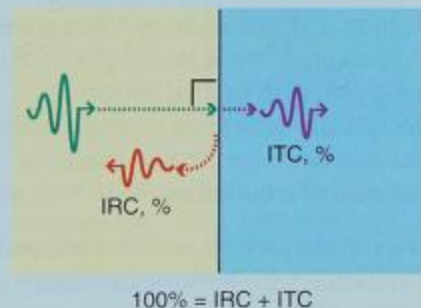


**Fig. 6.16** Whatever sound is not reflected must be transmitted.

| Questions                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Sound is traveling from bone to soft tissue. The impedances of the media differ significantly, and 90% of the beam's intensity is reflected. What percentage of the intensity is transmitted?                                                                                 | 1. 100% of the energy must be accounted for. If 90% is reflected, <b>10%</b> must be transmitted.                                                                                                                   |
| 2. Sound that is traveling in Jell-O passes through an interface at 90 degrees and continues to travel in whipped cream. The impedance of Jell-O and whipped cream are nearly identical. What percentage of the intensity is transmitted?<br>A. 2%<br>B. 25%<br>C. 78%<br>D. 99% | 2. D. The best choice is 99%. If the impedances of Jell-O and whipped cream are nearly identical, only a very small percentage of the sound beam's intensity will reflect. The remainder, of course, will transmit. |

## Reflection and Transmission with Oblique Incidence

With **normal incidence**, the study of reflection and transmission when sound strikes an interface is straightforward. Simply put, with normal incidence, reflection depends upon an impedance difference between the two media on either side of a boundary.

However, the physics of reflection and transmission with **oblique incidence** is complex. It is so complicated that we cannot predict whether sound will reflect or transmit after striking a boundary obliquely (see Fig. 6.17).

With oblique incidence, reflections may occur even when the impedances of the two media are identical. Furthermore, reflections may be absent even when the impedances are different. It is best to

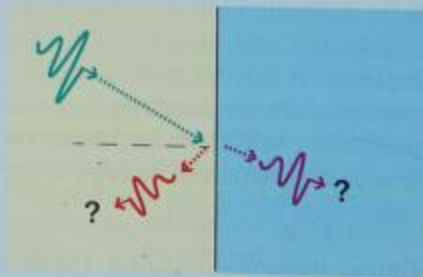


**Fig. 6.17** With oblique incidence, we cannot predict whether sound will reflect or transmit after striking a boundary.

consider the physics of reflection and transmission with oblique incidence as entirely unrelated to that with normal incidence.

## Reflection with Oblique Incidence

When a sound beam strikes a boundary obliquely, reflection may or may not occur. The presence of reflection is difficult to predict because the physics is complex.

Similarly, when a sound beam strikes a boundary obliquely, transmission may or may not occur. The presence of transmission is difficult to predict. No simple rules describe the processes of reflection and transmission.

However, two physical principles always apply to reflection with oblique incidence (see Fig. 6.18):

1. conservation of energy
2. reflection angle = incident angle

### 1. Conservation of Energy

The law of conservation of energy must apply with oblique incidence. That is, the sum of the percentage of sound reflected and the percentage of sound transmitted must equal 100%:

$$100\% = \text{reflection coefficient} + \text{transmission coefficient}$$

Similarly, the sum of the reflected and transmitted intensities must equal the incident intensity. Intensity has units of  $\text{watts/cm}^2$ .

$$\text{incident intensity (W/cm}^2\text{)} = \text{reflected intensity} + \text{transmitted intensity}$$

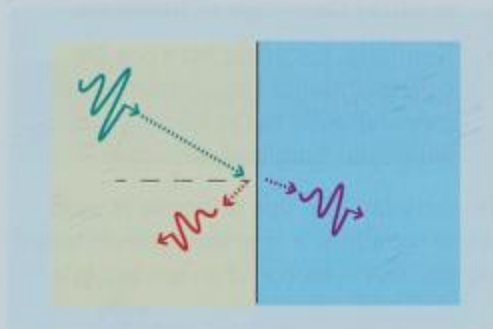


**Fig. 6.18** When a sound beam strikes a boundary with oblique incidence, the reflection angle equals the incident angle. Also, there is conservation of energy.



## 2. Reflection Angle = Incident Angle

When reflection occurs with oblique incidence, the sound beam is not redirected back toward the transducer. Rather, the beam is reflected in a different direction.

The direction of the reflected echo is equal and opposite to the direction of the incident beam (see Fig. 6.19).

angle of incidence = angle of reflection

- The angle between the incident sound beam and an imaginary line that is perpendicular to the boundary is called the “angle of incidence.”
- Similarly, the angle between the reflected sound beam and the line perpendicular to the boundary is called the “angle of reflection.”

In everyday life, this principle is used when we adjust a rear view mirror to see out the rear window of an automobile.

## Transmission with Oblique Incidence

When a sound beam strikes an interface at an oblique angle, transmission of any (or all) of the beam is uncertain. If, however, part of the wave is transmitted, the wave might travel straight ahead. Alternatively, the sound beam might bend or change direction. This bending phenomenon is called **refraction** (see Fig. 6.20).

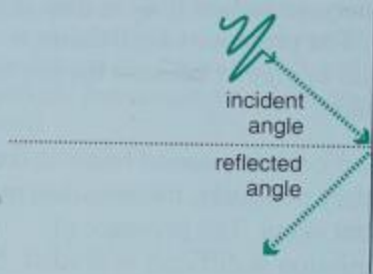


**Fig. 6.19** With oblique incidence, the angle of the reflection is equal to the angle of incidence.

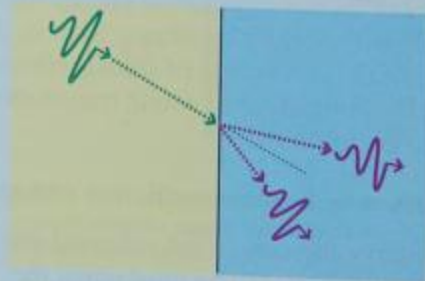


**Fig. 6.20** Refraction is transmission with a bend as illustrated in both purple pulses.



## Refraction

**Refraction** is a change in direction of wave propagation when traveling from one medium to another. Refraction is a process associated with transmission and occurs with light waves as well as sound waves. A straight pencil sitting in a glass of water may appear to be bent as a result of refraction (see Fig. 6.21).

Refraction occurs only if two conditions are satisfied:

1. oblique incidence (not normal), and
2. different propagation speeds of the two media

If transmission occurs and these two conditions are met, then the sound wave will never travel in a straight line but will bend. See Fig. 6.22.

Under clinical conditions, a sound beam will bend, at most, a few degrees at a soft tissue–fat interface, a muscle–blood interface, or a soft tissue–fluid interface, because the speed of sound in these media are similar.

On the other hand, bending is exaggerated at a bone–soft tissue interface because the speed of sound in bone is nearly three times greater than that in soft tissue.

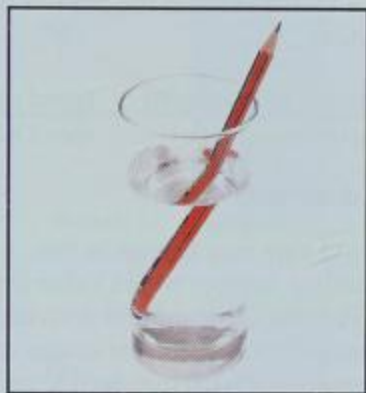


**Fig. 6.21** The light beam is refracted, creating the impression of a split in the pencil.

**Note:** Refraction is transmission with a bend.

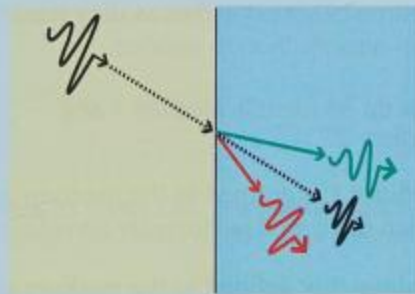


**Fig. 6.22** The red and green transmitted waves have undergone refraction. The black wave has not.

## Snell's Law

Snell's Law quantifies the physics of refraction:

$$\frac{\sin(\text{transmission angle})}{\sin(\text{incident angle})} = \frac{\text{speed of Medium 2}}{\text{speed of Medium 1}}$$

### *What does "sine" mean?*

The term **sine** may be new to you. A sine is a unitless number with a value from 0 to 1. The sine of an angle is derived from the mathematical theory of angles called *trigonometry*. The actual derivation of sine is beyond the scope of this textbook; it is important only to know that every angle has an associated sine that can be found in a reference table.

Although calculations using Snell's Law are not required, it is important to understand the concepts of refraction. There is merit in the following nonmathematical discussion of the bending of sound waves as they transmit from one medium to another.

### *How do we identify Medium 1 and Medium 2?*

Medium 1 is defined as the medium in which the sound is currently traveling.

Medium 2 is defined as the medium into which the sound is entering.

**Under what conditions will the transmission angle equal the incident angle?**

Recall the conditions for refraction:

- oblique incidence, and
- different propagation speeds

Refraction will not occur when the speeds of the two media are identical. The angles of incidence and transmission will be equal and the beam travels straight ahead (see Fig. 6.23A).

**Under what conditions will the transmission angle be greater than the incident angle?**

The transmission angle will be greater than the incident angle when the speed of Medium 2 is greater than the speed of Medium 1 (see Fig. 6.23B).

**Under what conditions will the transmission angle be less than the incident angle?**

The transmission angle will be less than the incident angle when the speed of Medium 2 is less than the speed of Medium 1 (see Fig. 6.23C).

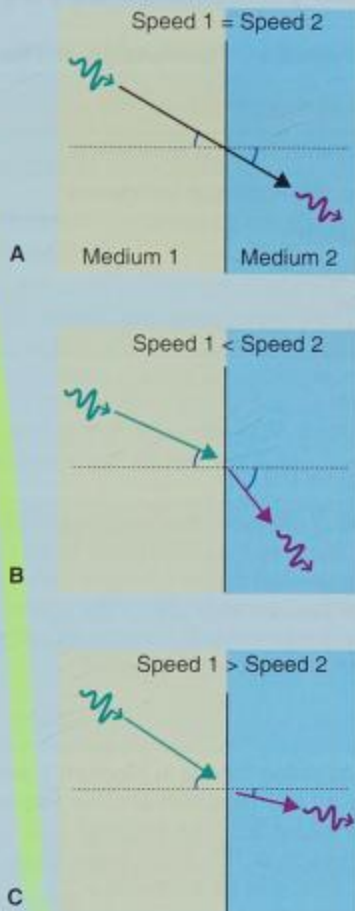


**Fig. 6.23** Snell's Law. The incident wave is green and the transmitted wave is purple.

**Table 6.6** Refraction and Speeds of Sound

| Speeds                       | Angle of Transmission                              |
|------------------------------|----------------------------------------------------|
| Speed 2 = Speed 1            | no refraction; transmission angle = incident angle |
| Speed 2 greater than Speed 1 | transmission angle greater than incident angle     |
| Speed 2 less than Speed 1    | transmission angle less than incident angle        |



## Summary: Reflection, Transmission, and Refraction

Table 6.7 Reflection, Transmission, and Refraction

| Event                             | Requirement                                                            |
|-----------------------------------|------------------------------------------------------------------------|
| Reflection with normal incidence  | different impedances required                                          |
| Reflection with oblique incidence | we cannot predict, it's too complex!                                   |
| Transmission                      | derived from reflection information; use law of conservation of energy |
| Refraction                        | oblique incidence and different speeds required                        |

| Questions                                                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                            |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. A pulse of ultrasound propagates in soft tissue, such as liver. The pulse strikes a soft tissue–soft tissue interface with oblique incidence. Some of the sound energy is transmitted. To what extent is the transmitted beam refracted?                                                                                                                                                         | 1. The transmitted beam undergoes little to no refraction. A transmitted beam is refracted when the incidence is oblique and the propagation speeds are different. Because the tissues on either side of the boundary are both “soft tissues,” their speeds are nearly identical and little or no refraction occurs.                                               |
| 2. A sound pulse travels in Medium 1 and strikes an interface with another tissue, Medium 2, at $30^\circ$ . The angle of transmission is $10^\circ$ . From these facts alone, what can be said about <ul style="list-style-type: none"> <li>• the speed of sound in Medium 1?</li> <li>• the speed of sound in Medium 2?</li> <li>• the difference between the speeds of Media 1 and 2?</li> </ul> | 2. Given only this information, we can say nothing about the speed of sound in Medium 1 or Medium 2. However, because the beam refracted significantly (there was a $20^\circ$ change in direction), the speeds of these two media are very different. Refraction depends on the <b>difference</b> in the speeds of sound in the two media, not the actual speeds. |
| 3. A sound pulse travels in Medium 1 and strikes an interface with another tissue, Medium 2, at $30^\circ$ . The angle of transmission is $10^\circ$ . In which medium does sound travel slowest? <ul style="list-style-type: none"> <li>A. Medium 1</li> <li>B. Medium 2</li> <li>C. cannot be determined</li> </ul>                                                                               | 3. B. Sound travels slowest in medium 2. When the angle of transmission is less than the angle of incidence, sound travels slower in the second medium.                                                                                                                                                                                                            |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>4. A sound pulse travels in Medium 1 and strikes an interface with another tissue, Medium 2, at <math>30^\circ</math>. The angle of transmission is <math>10^\circ</math>. In which medium is the impedance higher?</p> <p>A. Medium 1<br/>B. Medium 2<br/>C. cannot be determined</p>                                                                                                                                             | <p>4. C. Refraction of sound at a boundary is unrelated to the impedances of the media. Therefore, with the information provided, it cannot be determined which material has the greater impedance.</p> <p>Refraction is affected by the speed of sound in the media.</p> |
| <p>5. Sound travels in a medium and orthogonally strikes a boundary with a different medium. Although sound waves traveling in the media have vastly different speeds, there is no refraction. How can this be?</p>                                                                                                                                                                                                                   | <p>5. With normal incidence, refraction cannot occur. Refraction occurs only when there are different speeds and oblique incidence. Both conditions must be met. In this example, the incidence is normal—no refraction can occur.</p>                                    |
| <p>6. A sound wave strikes a boundary with normal incidence. The impedances of the two media are identical. What percentage of the sound wave is refracted?</p> <p>A. 100%<br/>B. 75%<br/>C. 0%<br/>D. 25%<br/>E. 90%</p>                                                                                                                                                                                                             | <p>6. C. Remember, refraction cannot occur with normal incidence.</p>                                                                                                                                                                                                     |
| <p>7. The impedance of Medium 1 is 8 rayls. The propagation speed is 1,450 m/s. The impedance of Medium 2 is 6 rayls and the speed is 1.855 km/s. A sound beam strikes the boundary between the media and is both partially transmitted and reflected. The angle of the incident beam is <math>30^\circ</math>. What is the reflection angle?</p>  | <p>7. <math>30^\circ</math>. This question is quite simple. The angle of reflection equals the angle of incidence.</p>                                                                                                                                                    |

## Review: Attenuation & Reflection

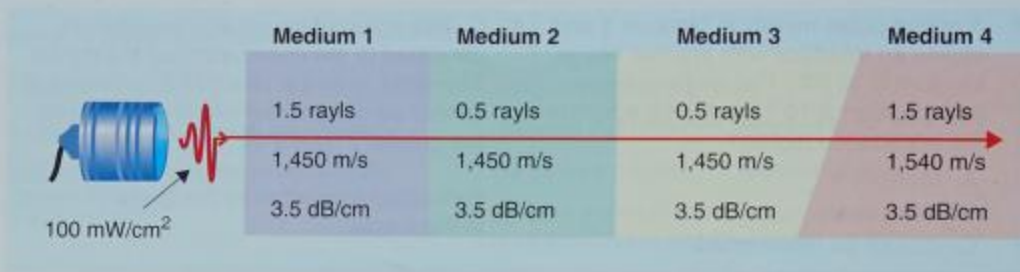


**Fig. 6.24** Use this figure to answer the following questions.

|                                                                                                                                                    |                                                                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. What does the 100 mW/cm <sup>2</sup> represent?                                                                                                 | 1. The incident intensity of the sound beam.                                                                                                           |
| 2. What does the 3.5 dB/cm represent?                                                                                                              | 2. The attenuation coefficient of the sound in the media.                                                                                              |
| 3. If the media are soft tissue, what is an estimate of the ultrasound frequency?                                                                  | 3. About 7 MHz; the attenuation coefficient multiplied by 2 approximates the frequency ( $3.5 \times 2 = 7$ ).                                         |
| 4. What property has units of rays? How is it determined?                                                                                          | 4. Impedance is calculated, not measured. Impedance = density x speed.                                                                                 |
| 5. The incidence between the sound wave and the boundary between Media 1 and 2 is normal. What happens at the boundary between Media 1 and 2? Why? | 5. Both reflection and transmission occur. There are normal incidence and different acoustic impedances.                                               |
| 6. The incidence between the sound wave and the boundary between Media 2 and 3 is normal. What happens at the boundary between Media 2 and 3? Why? | 6. Transmission only. The impedances of the media are the same.                                                                                        |
| 7. What type of incidence is there between Media 3 and 4?                                                                                          | 7. Oblique.                                                                                                                                            |
| 8. What happens at the boundary between Media 3 and 4? Why?                                                                                        | 8. Reflection may occur. If transmission does occur, the sound beam will refract because there are different propagation speeds and oblique incidence. |
| 9. What processes occur as the ultrasound passes through all media? What are the units of this process?                                            | 9. Attenuation (scattering, absorption, and reflection). Units: dB.                                                                                    |

## Range Equation

To create an anatomic image, a sound pulse must travel to a reflector located in the body and return to the transducer. The travel time of this journey allows us to accurately position the reflector.

### Time-of-Flight or Go-Return Time

Ultrasound systems determine reflector depth by measuring a pulse's time-of-flight with a very accurate stopwatch.

The elapsed time from pulse creation to pulse reception is called the **go-return time or time-of-flight**. When a reflector is located superficially, the time from pulse creation to reception is brief, whereas trips to and from deeper reflectors require more time. This is the basis for measuring distances in diagnostic imaging (see Fig. 7.1).

The **time-of-flight is directly related to how deep** a sound pulse travels. Greater distances prolong the time-of-flight; lesser distances shorten the time-of-flight.

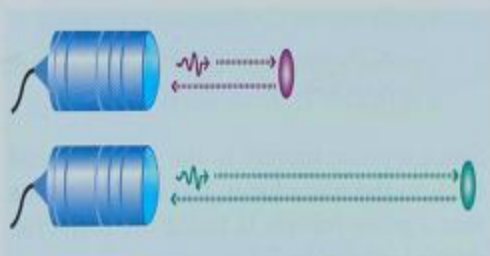


**Fig. 7.1** Time-of-flight of an ultrasound pulse is shorter for shallower reflectors (purple) and longer for deeper reflectors (green).



Ultrasound systems' computers are programmed with the average speed of sound in soft tissue, 1.54 mm/ $\mu$ s. Since the average speed of sound in soft tissue is known, the time-of-flight and distance that the pulse travels are directly related.

In fact, the depth of a reflector can be accurately calculated from the go-return time using the following equation:

$$\text{depth (mm)} = \frac{1.54 \text{ mm}/\mu\text{s} \times \text{go-return time } (\mu\text{s})}{2}$$

**Note:** When one reflector is twice as deep as another reflector, the pulse's time-of-flight is twice as long for the deeper reflector.

## The 13-Microsecond Rule

The 13-microsecond rule always applies when sound travels through soft tissue. For every 13  $\mu$ s of go-return time, the object creating the reflection is 1 centimeter deeper in the body.

For example:

- a pulse's time-of-flight is 26  $\mu$ s when a reflector is 2 cm deep
- a pulse's time-of-flight is 39  $\mu$ s when a reflector is 3 cm deep

Since a pulse travels to the reflector and back to the transducer, the total distance that a pulse travels is twice the reflector depth (see Table 7.1).

Table 7.1 13-Microsecond Rule

| Time of Flight | Reflector Depth | Total Distance Traveled |
|----------------|-----------------|-------------------------|
| 13 $\mu$ s     | 1 cm            | 2 cm                    |
| 26 $\mu$ s     | 2 cm            | 4 cm                    |
| 39 $\mu$ s     | 3 cm            | 6 cm                    |
| 52 $\mu$ s     | 4 cm            | 8 cm                    |
| 130 $\mu$ s    | 10 cm           | 20 cm                   |



## Pulse Repetition Period and Maximum Imaging Depth

When a sonographer adjusts a system's maximum imaging depth, the pulse repetition period is altered (see Fig. 7.2).

Recall that the pulse repetition period (PRP) is the time from the start of one pulse to the start of the next pulse. Therefore, the pulse repetition period is the go-return time of a sound pulse between the transducer and the bottom of the image. The 13-microsecond rule applies.

- When the depth of view is shallow, PRP is short.
- When the depth of view is deep, PRP is long.

Mathematically, in soft tissue:



$$\text{PRP } (\mu\text{s}) = \text{imaging depth (cm)} \times 13 \mu\text{s/cm}$$

For example:

- When the depth of view is set to 10 cm, PRP is 130  $\mu\text{s}$  ( $10 \times 13 \mu\text{s}$ ).
- When the depth of view is set to 5 cm, PRP is 65  $\mu\text{s}$  ( $5 \times 13 \mu\text{s}$ ).

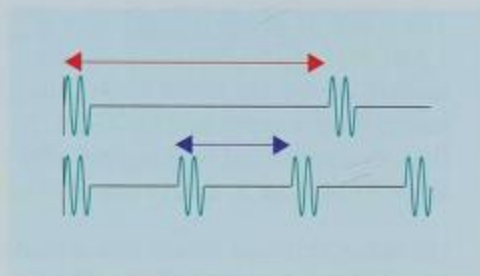


**Fig. 7.2** When the imaging depth is deep, pulse repetition period is long, upper pattern, red line. When the imaging depth is shallow, pulse repetition period is short, lower pattern, blue line.

**Note:** Pulse repetition period (PRP) is directly related to the maximum imaging depth.

## Pulse Repetition Frequency (PRF) and Maximum Imaging Depth

The speed of sound in soft tissue is 1,540 m/s, or 154,000 cm/s. In one second, sound can travel into tissue and return from a depth of 77,000 cm. At first, this statement may appear silly since 77,000 cm is nearly one-half mile.

However, this also means that sound can travel to and from a depth of 77 cm a total of 1,000 times in 1 second, or to and from a depth of 7.7 cm a total of 10,000 times in 1 second.

In essence, 77,000 cm may be a single round trip, or divided into many thousands of round trips.

- When the depth of view is shallow, PRF is high.
- When the depth of view is deep, PRF is low.

Mathematically, in soft tissue:

$$\text{PRF (Hz)} = \frac{77,000 \text{ cm/s}}{\text{imaging depth (cm)}}$$

For example:

- When the depth of view is set to 7.7 cm, PRF is 10,000 Hz ( $77,000 / 7.7 = 10,000$ ).
- When the depth of view is set to 15.4 cm, PRF is 5,000 Hz ( $77,000 / 15.4 = 5,000$ ).

**Note:** Pulse repetition frequency (PRF) is inversely related to the maximum imaging depth.

## Review: Range Equation

| Questions                                                                                                                                                                                                                                                              | Answers                                                                                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| 1. A sound wave is created by a transducer, reflects off an object, and returns to the transducer. The depth of the reflector is 10 cm in soft tissue. What is the go-return time?<br>A. 13 $\mu$ s<br>B. 1.3 $\mu$ s<br>C. 65 $\mu$ s<br>D. 130 $\mu$ s               | 1. D. Time of flight equals depth multiplied by 13 $\mu$ s.<br>$10 \text{ cm} \times 13 \mu\text{s/cm} = 130 \mu\text{s}$        |
| 2. A sound wave is created by a transducer, reflects off an object, and returns to the transducer. The go-return time is 26 $\mu$ s. What is the depth of the reflector?<br>A. 1 cm<br>B. 2 cm<br>C. 3 cm<br>D. 4 cm                                                   | 2. B. The reflector depth is 2 cm.<br>$2 \text{ cm} \times 13 \mu\text{s/cm} = 26 \mu\text{s}$                                   |
| 3. A sound wave is created by a transducer, reflects off an object, and returns to the transducer. The go-return time is 26 $\mu$ s. What is the total distance that the pulse traveled?<br>A. 1 cm<br>B. 2 cm<br>C. 3 cm<br>D. 4 cm                                   | 3. D. Total distance traveled is twice the depth of the reflector.                                                               |
| 4. The maximum imaging depth (depth of view) during an ultrasound exam is 10 cm. The sonographer adjusts the imaging depth to 20 cm. What happens to pulse repetition period?<br>A. it is unchanged<br>B. it is halved<br>C. it is doubled<br>D. it is 20 times longer | 4. C. Pulse repetition period is directly related to imaging depth. When imaging depth doubles, pulse repetition period doubles. |

| Questions                                                                                                                                                                                                                                                                          | Answers                                                                                                                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| <p>5. The maximum imaging depth during an ultrasound exam is 10 cm. The sonographer adjusts the imaging depth to 20 cm. What happens to pulse repetition frequency?</p> <p>A. it is unchanged<br/>B. it is halved<br/>C. it is doubled<br/>D. it is 20 times longer</p>            | <p>5. B. Pulse repetition frequency is inversely related to imaging depth. When imaging depth doubles, PRF is halved.</p> |
| <p>6. The imaging depth during an ultrasound exam is 10 cm. The sonographer adjusts the imaging depth to 5 cm. What happens to pulse repetition period?</p> <p>A. it is unchanged<br/>B. it is halved<br/>C. it is doubled<br/>D. it is 20 times longer</p>                        | <p>6. B. Pulse repetition period is directly related to imaging depth. When imaging depth is halved, PRP is halved.</p>   |
| <p>7. A sound wave is created by a transducer, reflects off an object, and returns to the transducer. The imaging depth is 10 cm in soft tissue. What is the maximum pulse repetition frequency?</p> <p>A. 7,700<br/>B. 7.7 kHz<br/>C. 3,500 Pa<br/>D. 7,700 <math>\mu</math>s</p> | <p>7. B. is the correct answer because the units are correct.</p>                                                         |
| <p>8. A sound wave is created by a transducer, reflects off an object, and returns to the transducer. The maximum imaging depth is 7.7 cm. What is the PRF?</p> <p>A. 7,700 Hz<br/>B. 5,000 kHz<br/>C. 10,000 Hz<br/>D. 100 <math>\mu</math>s</p>                                  | <p>8. C.<br/><math>77,000 / 7.7 = 10,000 \text{ Hz}</math>.</p>                                                           |
| <p>9. A sound wave is created by a transducer, reflects off an object, and returns to the transducer. The go-return time is 130 <math>\mu</math>s. What is the maximum PRF?</p> <p>A. 7,700 Hz<br/>B. 5,000 kHz<br/>C. 10 cm<br/>D. 100 <math>\mu</math>s</p>                      | <p>9. A.</p>                                                                                                              |



# Transducers

A transducer is any device that **converts one form of energy into another**.

Table 8.1 lists examples of transducers.

Ultrasound transducers perform two functions:

- During **transmission**, electrical energy from the system is converted into sound.
- During **reception**, the reflected sound pulse is converted into electricity.

## Piezoelectric Effect

The piezoelectric effect describes the property of certain materials to create a voltage when they are mechanically deformed or when pressure is applied to them.

In addition, piezoelectric materials change shape when a voltage is applied to them, a process called the **reverse piezoelectric effect**.

Table 8.1 Transducer Examples

| Transducer          | Converts   |              |
|---------------------|------------|--------------|
|                     | from...    | to...        |
| ultrasound transmit | electrical | acoustic     |
| ultrasound receive  | acoustic   | electrical   |
| car engine          | chemical   | motion       |
| electric motor      | electrical | motion       |
| light bulb          | electrical | light & heat |
| muscle              | chemical   | motion       |

## Piezoelectric Materials

Materials which convert sound into electricity (and vice versa) are called **piezoelectric** or **ferroelectric**.

Some piezoelectric materials (quartz and tourmaline) are found in nature, but those commonly used in clinical transducers, **lead zirconate titanate** or **PZT**, are synthetic or man-made.

## Synonyms

PZT in an ultrasound transducer is also known as the **ceramic, active element, or crystal**.

## Basic Transducer Construction

Modern ultrasound transducers used in the clinical environment are elaborate. However, they share many of their design characteristics with simple, single crystal, unfocused probes. The design of these simple probes helps us understand transducer characteristics and function.

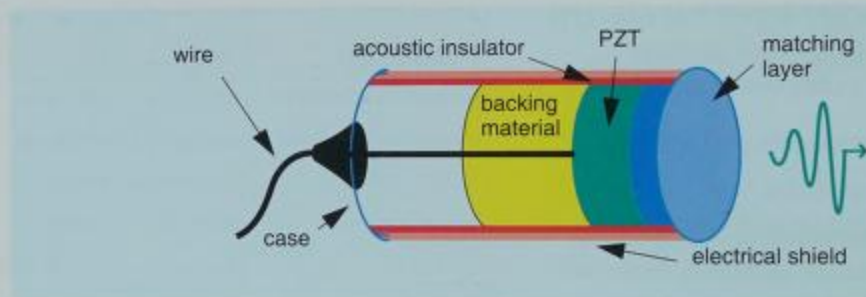


**Fig. 8.1** Seven components of a basic ultrasound transducer. Refer to Table 8.2 on page 115.

A basic ultrasound transducer has the appearance of a cylindrical tube. A sound pulse is emitted from the front of the tube, which is placed on the skin. A wire connecting the transducer to the ultrasound system, extends from the back of the cylinder.

A basic transducer has seven components (see Fig. 8.1):

Table 8.2 Transducer Components

| Component                                          | Description                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| case                                               | The cylindrical tube, constructed of metal or plastic, that protects the internal components of the transducer from damage. The case also insulates the patient from electrical shock.                                                                                                                                                                                                                                                            |
| electrical shield                                  | A thin metallic barrier lining the inside of the case. The shield prevents spurious electrical signals in the air, unrelated to diagnostic information, from entering the transducer. Thus, the shield helps prevent electrical noise from contaminating the clinically important electrical signals used to create diagnostic images. In Fig. 8.1, the electrical shield is orange.                                                              |
| acoustic insulator                                 | A thin barrier of cork or rubber that isolates or "uncouples" the internal components of the transducer from the case. The acoustic insulator prevents vibrations in the case from inducing an electrical voltage in the PZT of the transducer. In Fig. 8.1, the acoustic insulator is red.                                                                                                                                                       |
| PZT or active element                              | The piezoelectric crystal itself. In a simple probe, the active element is shaped like a coin. The characteristics of the sound beam emitted by the transducer are related to the dimensions of the active element. The piezoelectric material (PZT) is one-half wavelength thick. In Fig. 8.1, the active element is green.                                                                                                                      |
| wire                                               | Provides an electrical connection between the PZT and the ultrasound system. The active element requires electrical contact so that during transmission, the voltage from the ultrasound system can cause the crystal to vibrate and produce an ultrasonic wave. Similarly, during reception, the crystal's vibration produces a voltage that must return to the system for processing into an image. In Fig. 8.1, the wire is black.             |
| matching layer                                     | Positioned in front of the PZT at the face of the transducer. The matching layer: <ul style="list-style-type: none"> <li>• increases the efficiency of sound energy transfer between the active element and the body, and</li> <li>• protects the active element.</li> </ul> The matching layer is one-quarter wavelength thick and appears as the blue material in Fig. 8.1.                                                                     |
| backing material (also called the damping element) | Bonded to the back of the active element, it reduces the "ringing" of the PZT. Backing material is commonly made of epoxy resin impregnated with tungsten filaments. When an electrical spike excites the PZT, the backing material restricts the extent of PZT deformation. The emitted sound pulse is dampened; thus, it is short in duration and length. Crystal damping enhances axial resolution. The damping element is yellow in Fig. 8.1. |



## Matching Layer

Recall that differences in impedance result in reflections at boundaries. Larger reflections occur with greater impedance differences (see page 95).

The impedance of PZT is about 20 times greater than the impedance of skin. If a sound beam travels directly from PZT to skin, the vast majority of the sound would reflect back into the PZT and never enter the body. Only a tiny percentage would transmit into the body. This inefficient transfer would seriously limit the clinical utility of such a transducer design.

The matching layer is designed with an impedance in between that of the active element and the skin. Thus, the matching layer decreases reflection at the PZT/skin boundary, thereby increasing the percentage of transmitted sound between the active element and the skin.

Similarly, the impedance of gel is between that of the matching layer and biologic media. Gel further increases the percentage of sound transmitted into and out of the body. That is why gel is commonly described as “coupling” the transducer to the patient.

**Note:** The matching layer and gel increase the efficiency of sound transfer between the transducer’s PZT and the skin.

In decreasing order of impedance:  
PZT > matching layer > gel > skin

*How thick are the matching layer and the active element of a basic ultrasound transducer?*

The thickness of the **matching layer is one-quarter of the wavelength** of sound in the matching layer.

The thickness of the **active element is one-half of the wavelength** of sound in the active element.

Table 8.3 Thickness of Components

| Component      | Thickness                      |
|----------------|--------------------------------|
| Active element | $\frac{1}{2}$ wavelength thick |
| Matching layer | $\frac{1}{4}$ wavelength thick |



## Backing Material

The backing material plays an essential role in optimizing the pulses created by imaging transducers.

With backing material, short pulses are produced by the transducer. Without damping material, the PZT crystal, when excited, will vibrate for a long time. The emitted pulse will be drawn out both in length and duration. Long pulses degrade axial resolution and create less accurate images.

In contrast, when damping material is attached to the PZT crystal, the crystal's vibration is substantially reduced. The sound pulse is short in length and duration, thereby providing enhanced axial resolution.

The characteristics of damping material include the following:

- high degree of sound absorption
- acoustic impedance similar to PZT

The impedances of the damping element and PZT are similar, so the sound wave created by the PZT moves into the damping material and away from the patient. The sound energy is absorbed in the backing material.

It is important to understand that the backing material affects the transducer in other ways.

*What are additional consequences related to the use of a backing material?*

Three consequences of using backing material are:

1. decreased sensitivity
2. wide bandwidth
3. low quality factor

### 1. Decreased Sensitivity

The backing material not only reduces active element vibration during transmission, but also reduces vibration during reception. This is undesirable because the transducers are less responsive to the tiny reflected sound waves returning from reflectors in the body.

**Decreased sensitivity** means that during reception, transducers with damping material are less able to convert low-level sound reflections into meaningful electrical signals.

## 2. Wide Bandwidth

When a guitar string is plucked, a long, pure tone of sound is produced. The tone is pure because the string vibrates freely for a long time at a single frequency, called the **resonant frequency**.

When backing material is applied to a vibrating object—in this case, the PZT crystal of an imaging transducer—the crystal is prohibited from vibrating freely. The PZT is restricted, and the pulse emitted by an imaging probe is a short duration sound “click” rather than a steady long tone.

The sound click, although short, contains sound at many different frequencies, both above and below the transducer’s main frequency. **Bandwidth** is the range of frequencies in the pulse. It is the difference between the highest and lowest frequencies.

Imaging probes produce pulses that are identified as **wide bandwidth** or **broadband**, green in Fig. 8.2. Other probes, such as those used in therapeutic ultrasound or continuous wave Doppler, do not use backing material and produce narrow bandwidth pulses; red in Fig. 8.2.

### Example:

A transducer with a 3 MHz main frequency produces a sound pulse that contains frequencies ranging from 1 MHz to 5 MHz. The bandwidth, or range of frequencies in the pulse, is  $5\text{ MHz} - 1\text{ MHz}$  or 4 MHz.

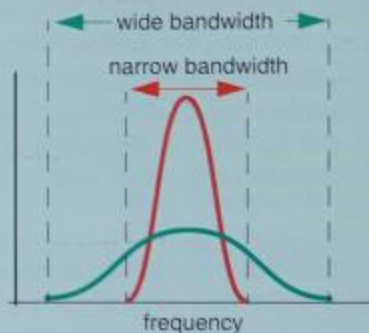


**Fig. 8.2** Imaging probes create a wide range of frequencies (green), whereas continuous wave probes create a narrow range of frequencies (red).

**Note:** As a general rule, long duration events are narrow bandwidth, whereas short duration events are wide bandwidth (broadband).

### 3. Low Quality Factor

**Quality factor** is a unitless number that is inversely related to bandwidth. Mathematically, the Q-factor is the main frequency divided by the bandwidth.

$$\text{quality factor} = \frac{\text{main frequency}}{\text{bandwidth}}$$

Wide bandwidth probes have a low Q-factor. Narrow bandwidth probes have a high Q-factor.

Because **imaging probes** use backing material and have a wide bandwidth, they are often referred to as **low-Q**.

Transducers used in therapeutic ultrasound and continuous wave Doppler do not contain backing material. They have a narrow bandwidth and high-Q.

#### Example:

In the previous example on page 118, a 3 MHz transducer with a bandwidth of 4 MHz has a Q-factor of  $\frac{3}{4}$ , or 0.75.

**Note:** To remember the relationship between damping and Q-factor, know that Q is directly related to the pulse length.

- A shorter, dampened pulse has a lower Q-factor.
- A longer, undamped pulse has a higher Q-factor.

Table 8.4 Imaging vs. Non-imaging Transducers

| Imaging Transducers                      | Non-Imaging Transducers                                           |
|------------------------------------------|-------------------------------------------------------------------|
| • pulses with short duration and length  | • creates continuous wave or pulses with long duration and length |
| • uses backing material to limit ringing | • no backing material                                             |
| • reduced sensitivity                    | • increased sensitivity                                           |
| • wide bandwidth or broadband            | • narrow bandwidth                                                |
| • lower Q-factor                         | • higher Q-factor                                                 |
| • improved axial resolution              | • cannot even create an image                                     |



## More About Piezoelectric Materials

### *How is PZT created?*

The piezoelectric properties of lead zirconate titanate (PZT) do not occur spontaneously. Rather, these properties are created by exposing the material to a strong electrical field while being heated to a substantial temperature. This process is called **polarization**.

### *What is the Curie temperature, and what is its importance?*

The temperature at which PZT is polarized is called the **Curie temperature** or **Curie point**, named after the scientists who discovered the piezoelectric effect.

Similarly, piezoelectric properties can be destroyed by exposure to high temperature. If the polarized PZT is heated above the Curie temperature, the crystal's piezoelectric properties are destroyed. The loss of piezoelectric properties is called **depolarization**, and the PZT is said to be **depolarized**.

### *What is the difference between sterilization and disinfection? Which method is used on transducers?*

**Sterilization** is the destruction of all microorganisms by exposure to extreme heat, chemical agents, or radiation.

**Disinfection** is the application of a chemical agent to reduce or eliminate infectious organisms on an object. Disinfection attempts to significantly reduce the microbial load.

Medical instruments differ in their potential to transmit infection.

Instruments that penetrate the skin or mucous membranes have the highest potential for transmitting infections. These instruments require sterilization.

Ultrasound transducers, which rarely penetrate mucous membranes, are less likely to transmit infection. These instruments require only disinfection. Endocavitary probes are even less critical since they are routinely covered with a single-use disposable barrier.

As a rule, transducers should be disinfected with Cidex™ or other cold germicides. Transducers should not be exposed to extreme temperatures so as to prevent depolarization of the PZT and a loss of piezoelectric properties. Even if the temperature does not exceed the Curie point, high temperatures may have other untoward effects, such as thermal damage to the adhesives and bonding agents used in transducer construction.



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. You are given 5 substances: backing material, PZT, matching layer, gel, and skin, whose impedances have been measured. Unfortunately, the labels identifying the impedance of each substance have fallen off these materials. There are five labels, indicating impedances of 0.8 Mrayls, 1.9 Mrayls, 1.6 Mrayls, 2.0 Mrayls and 1.0 Mrayls. If the impedance of the backing material is 1.9 Mrayls, what are the impedances of soft tissue, matching layer, gel, and PZT? Why? | <p>1. The impedances of the substances are:</p> <ul style="list-style-type: none"> <li>• PZT—2 Mrayls</li> <li>• matching layer—1.6 Mrayls</li> <li>• gel—1.0 Mrayls, and</li> <li>• skin—0.8 Mrayls.</li> </ul> <p>The impedance of the active element is similar to that of the backing material. To optimize the efficiency of sound energy transfer between the transducer and the body, the impedances of the materials along the path from the PZT to the skin will decrease in order; the highest impedance will be that of the PZT, then the matching layer, then gel, and finally the skin.</p> |
| 2. Pulse length is [directly or inversely] related to pulse duration.                                                                                                                                                                                                                                                                                                                                                                                                              | 2. directly.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| 3. Q-factor is [directly or inversely] related to bandwidth.                                                                                                                                                                                                                                                                                                                                                                                                                       | 3. inversely.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 4. Pulse duration is [directly or inversely] related to bandwidth.                                                                                                                                                                                                                                                                                                                                                                                                                 | 4. inversely.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 5. The sensitivity of transducers that create short duration pulses is likely to be [greater than, less than, or equal to] that of transducers that create long pulses.                                                                                                                                                                                                                                                                                                            | 5. less than.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 6. All of the following correctly describe an imaging transducer <i>except</i> :<br>A. high sensitivity<br>B. low Q<br>C. wide bandwidth<br>D. damped                                                                                                                                                                                                                                                                                                                              | 6. A. Choice A does <i>not</i> describe imaging transducers. Imaging transducers have a low sensitivity.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 7. T or F. Shorter duration events (such as dampened pulses) are more likely to be wide bandwidth.                                                                                                                                                                                                                                                                                                                                                                                 | 7. True. Short duration events are likely to be wide bandwidth. Longer events are more likely to be narrow bandwidth.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 8. What occurs when a PZT crystal's temperature is elevated above the Curie point?                                                                                                                                                                                                                                                                                                                                                                                                 | 8. When PZT's temperature exceeds the Curie point, the PZT is depolarized. The crystal's piezoelectric properties are lost forever and the transducer is ruined.                                                                                                                                                                                                                                                                                                                                                                                                                                         |

## Transducer Frequencies

*What determines the frequency of sound produced by a transducer?*

Interestingly, the answer differs depending on whether the transducer produces continuous wave sound or pulses.

### Continuous Wave Transducers

A continuous wave ultrasound system produces a continuous electrical signal that constantly excites or drives the active element in the transducer. The frequency of sound emitted by a continuous wave probe is equal to the frequency of the electrical signal (see Fig. 8.3).

electrical frequency = acoustic frequency

#### Example

What is the frequency of sound from a continuous wave transducer when the transmitter creates a 6 MHz electrical signal?

The transmitter of a continuous wave ultrasound system creates an electrical signal that continuously excites the PZT. The electrical signal's frequency is 6 MHz; therefore, the acoustic frequency is 6 MHz.



**Fig. 8.3** The frequency of sound that a **continuous wave** transducer emits is determined by the frequency of the electrical signal created by the ultrasound system.

## Pulsed Wave Transducers

A pulsed wave ultrasound system creates a short duration electrical spike that travels through the wire and strikes the PZT crystal in the transducer. This process is similar to quickly striking the key of a piano with your finger and creating a sound pulse.

When a key is depressed on a piano, a small hammer strikes a piano string, creating a sound pulse. The frequency of the piano's sound depends upon the characteristics of the piano string. Similarly, the frequency of sound created by the active element of a pulsed wave transducer depends upon the characteristics of the active element in the transducer.

***What characteristics of the active element determine the frequency of sound created by a pulsed wave transducer?***

With a pulsed wave transducer, two characteristics of the active element combine to determine the frequency of sound:

1. speed of sound in the PZT **Directly**
2. thickness of the PZT **Inversely**

### 1. How does the speed of sound in PZT affect frequency?

In a pulsed wave transducer, the speed of sound in PZT and the frequency of sound are directly related. When the speed of sound in PZT is faster, the frequency of sound created by a pulsed wave transducer is higher. When sound's speed in PZT is slower, the frequency is lower (see Fig. 8.4).

The speed of sound in most piezoelectric material ranges from 4 to 6 mm/ $\mu$ s (about 4 times greater than the speed of sound in soft tissue). This value is a characteristic of each piece of PZT and cannot be changed.

This concept is illustrated in Fig. 8.4. The PZT crystals of the transducers are colored orange and green. The speed of sound in the orange PZT material is slower than that in the green PZT. Thus, the frequency of sound created by the orange-colored PZT is lower than that of the green-colored PZT.

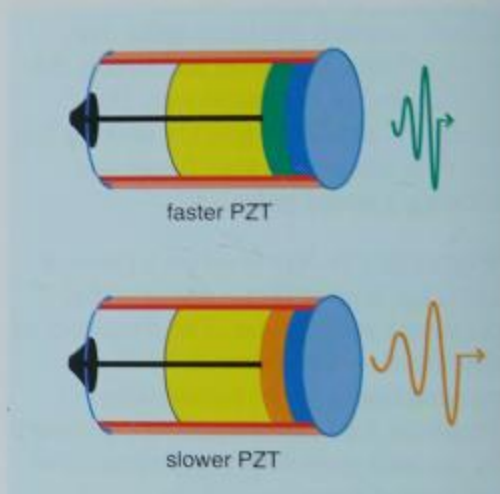


**Fig. 8.4** Relationship between speed of sound in PZT and the frequency of the emitted sound pulse. Sound travels faster in the green PZT crystal and the frequency of sound is higher. The sound travels slower in the orange PZT, which creates lower frequency sound.



## 2. How does the thickness of the PZT crystal affect frequency?

For pulsed wave transducers, thinner active elements create higher frequency sound pulses. That is, **PZT thickness and frequency are inversely related** (see Fig. 8.5).

Thinner active elements create pulses with higher frequency, shorter wavelength cycles. Thicker active elements create pulses with lower frequency, longer wavelength cycles.

This concept is illustrated in Fig. 8.5. Other than thickness, the two green PZT crystals are identical. The thinner crystal produces higher frequency sound pulses. The thicker crystal produces lower frequency sound pulses.

Transducer manufacturers create PZT crystals of varying thickness, thereby designing transducers of different frequencies. The thickness of PZT crystals in diagnostic imaging transducers range from 0.2 to 1 mm.

**Table 8.5 Frequency of Pulsed Wave Imaging Transducers**

| Characteristics of High Frequency Pulsed Wave Imaging Transducers | Characteristics of Low Frequency Pulsed Wave Imaging Transducers |
|-------------------------------------------------------------------|------------------------------------------------------------------|
| • thinner PZT crystals                                            | • thicker PZT crystals                                           |
| • PZT with higher speeds                                          | • PZT with lower speeds                                          |

The mathematical relationship is:

$$\text{frequency (MHz)} = \frac{\text{sound's speed in PZT (mm/}\mu\text{s)}}{2 \times \text{thickness (mm)}}$$

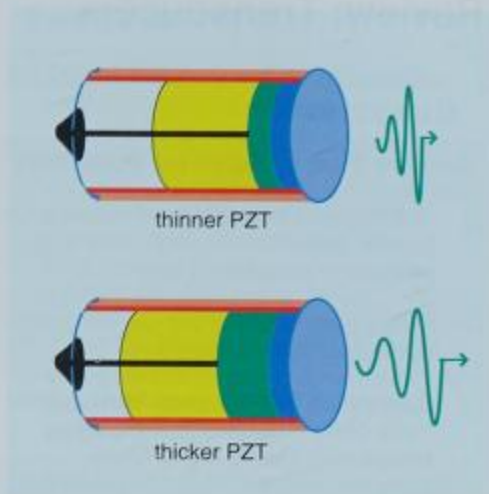


**Fig. 8.5** Thinner PZT crystals create sound pulses with higher frequencies. Thicker PZT crystals create sound pulses with lower frequencies.

**Hint:** The thickness of the PZT crystal in a pulsed wave transducer is equal to one-half of the wavelength of sound in the PZT.

## Review: Transducers

| Questions                                                                                                                                                | Answers                                                                                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| <b>Answer True or False for questions 1–18:</b>                                                                                                          |                                                                                                                    |
| 1. The acoustic impedance of the matching layer is approximately the same as the acoustic impedance of skin.                                             | 1. False. The impedance of the matching layer is greater than the impedance of the skin.                           |
| 2. Imaging transducers are usually of high rather than low bandwidth.                                                                                    | 2. True. Imaging transducers are high or wide bandwidth (broadband).                                               |
| 3. A very high Q factor transducer is used more often in diagnostic imaging transducers than a low Q factor.                                             | 3. False. Imaging transducers are low-Q.                                                                           |
| 4. A pulse with a long pulse duration is likely to have a narrow bandwidth.                                                                              | 4. True. Longer events tend to have a narrow bandwidth. Shorter events tend to have wider bandwidth.               |
| 5. The damping material in a transducer increases the sensitivity.                                                                                       | 5. False. Damping reduces sensitivity.                                                                             |
| 6. The damping material in a transducer increases the pulse length.                                                                                      | 6. False. Damping shortens pulse length.                                                                           |
| 7. The damping material in a transducer decreases the pulse duration.                                                                                    | 7. True. Damping decreases pulse duration.                                                                         |
| 8. The damping material in a transducer improves the system's lateral resolution.                                                                        | 8. False. Damping does not affect lateral resolution.                                                              |
| 9. The damping material in a transducer improves the system's longitudinal resolution.                                                                   | 9. True. Damping improves longitudinal resolution.                                                                 |
| 10. The damping material in a transducer decreases the bandwidth.                                                                                        | 10. False. Damping increases bandwidth.                                                                            |
| 11. The damping material in a transducer decreases the quality factor.                                                                                   | 11. True. Damping decreases the Q-factor.                                                                          |
| 12. If the frequency of the electrical excitation voltage of a pulsed wave transducer is 6 MHz, then the operating frequency of the transducer is 6 MHz. | 12. False. With <b>pulsed wave</b> transducers, the frequency of sound is not determined by the electrical signal. |



| Questions                                                                                                                                                                                                                                                              | Answers                                                                                                                                       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 13. If the pulse repetition frequency of a transducer is increased, then the frequency of sound produced by the transducer remains the same.                                                                                                                           | 13. True. Frequency and pulse repetition frequency are not related.                                                                           |
| 14. The diameter of the active element of a transducer helps to determine the frequency of the sound that the transducer creates.                                                                                                                                      | 14. False. The diameter of the active element does not determine the frequency of sound created by the transducer.                            |
| 15. If the frequency of the electrical excitation voltage of a continuous wave transducer is 6 MHz, then the operating frequency of the transducer is 6 MHz.                                                                                                           | 15. True. The frequency of the electrical voltage and the frequency of the sound beam are identical with <b>continuous wave transducers</b> . |
| 16. Two piezoelectric crystals are made from the same material. The thicker crystal will make a pulsed transducer with a higher frequency.                                                                                                                             | 16. False. Thicker active elements create sound with lower frequency, not higher.                                                             |
| 17. Two piezoelectric crystals are made from the same material. The thicker crystal will make a <b>continuous wave</b> transducer with a lower frequency.                                                                                                              | 17. False. With a <b>continuous wave</b> transducer, active element thickness does not determine the sound beam's frequency.                  |
| 18. The normal propagation speed in piezoelectric material is about 3 to 5 times greater than that in soft tissue.                                                                                                                                                     | 18. True. Sound travels much faster in PZT than in soft tissue.                                                                               |
| 19. The impedance of a transducer active element is 1,900,000 Rayls, and the impedance of the skin is 1,400,000 Rayls. What is an acceptable impedance for the matching layer?<br>A. 1,200,000 Rayls<br>B. 1,400,000 Rayls<br>C. 1,726,000 Rayls<br>D. 1,950,000 Rayls | 19. C. The impedance of the matching layer is between that of the active element and the skin.                                                |
| 20. Which of the following crystals will produce sound with the lowest frequency?<br>A. thin and with a low speed<br>B. thin and with a high speed<br>C. thick and with a low speed<br>D. thick and with a high speed                                                  | 20. C. Sound with the lowest frequency is produced by a thick active element in which sound travels slowly.                                   |

| Questions                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 21. Which type of transducer has a greater Q-factor: therapeutic or imaging?                                                                                                                                                     | 21. Therapeutic transducers have a higher Q-factor than imaging transducers.                                                                                                                                                                                   |
| 22. Which type of transducer has a greater bandwidth: continuous wave or imaging?                                                                                                                                                | 22. Imaging transducers have a wider bandwidth than continuous wave transducers.                                                                                                                                                                               |
| 23. Which type of transducer has more backing material: therapeutic or imaging?                                                                                                                                                  | 23. Imaging transducers use more backing material than therapeutic transducers.                                                                                                                                                                                |
| 24. In an imaging transducer, what is the purpose of attaching the backing material to the PZT?<br>A. increase the bandwidth<br>B. decrease the Q-factor<br>C. improve image quality<br>D. decrease the transducer's sensitivity | 24. C. The purpose of the backing material in imaging transducers is to improve image quality.                                                                                                                                                                 |
| 25. A pulsed-wave transducer has a resonant frequency of 5 MHz. The lowest frequency in the pulse is 2 MHz and the highest is 8 MHz. What is the bandwidth?<br>A. 5 MHz<br>B. 8 MHz<br>C. 3 MHz<br>D. 6 MHz<br>E. 2 MHz          | 25. D. Bandwidth is the range of frequencies found in a pulse. In this case, $8 \text{ MHz} - 2 \text{ MHz} = 6 \text{ MHz}$ .                                                                                                                                 |
| 26. For the transducer described in question 25, what is the main frequency?<br>A. 5 MHz<br>B. 8 MHz<br>C. 3 MHz<br>D. 6 MHz<br>E. 2 MHz                                                                                         | 26. A. The resonant, main, or center frequency is 5 MHz.                                                                                                                                                                                                       |
| 27. For the transducer described in question 25, what is the Q-factor?<br>A. 0.8<br>B. 3 MHz<br>C. 5 MHz<br>D. 1.5<br>E. 2 MHz                                                                                                   | 27. A. Q-factor is resonant frequency divided by bandwidth, $5 \text{ MHz} / 6 \text{ MHz}$ . Bandwidth has no units.<br><br><b>Note:</b> No calculations are needed to answer this question as choice A is the only unitless answer with a value less than 1. |



## Sound Beams

The shape of a sound beam is described in this chapter. Our discussion is limited to a beam created by a single disc-shaped, unfocused PZT crystal operating in the continuous wave mode.

In diagnostic ultrasound, the active element is *not typically in the shape of a disc*. Moreover, when used to create anatomic images the active element does not operate in the continuous wave mode. Nonetheless, this description provides the foundation for understanding the shape and behavior of sound beams used in clinical imaging.

Specifically, we will address the following questions:

- What is the overall shape of a sound beam?
- What are the regions of a beam called?
- What characteristics of a crystal determine the depth of the beam's focus?
- What characteristics of a crystal determine the degree to which the beam spreads?

## Shape of a Sound Beam

As sound travels, the width of the beam changes (see Fig. 9.1). At the starting point, the beam width is exactly the same as the transducer diameter. The beam narrows progressively, like a funnel, until it reaches its smallest diameter. After that, the beam expands or diverges.



**Fig. 9.1** Beam created by a disc-shaped crystal producing continuous sound.

## Anatomy of a Sound Beam

Five terms describe the shape and regions of a sound beam:

1. focus
2. near zone
3. focal length or near zone length
4. far zone
5. focal zone

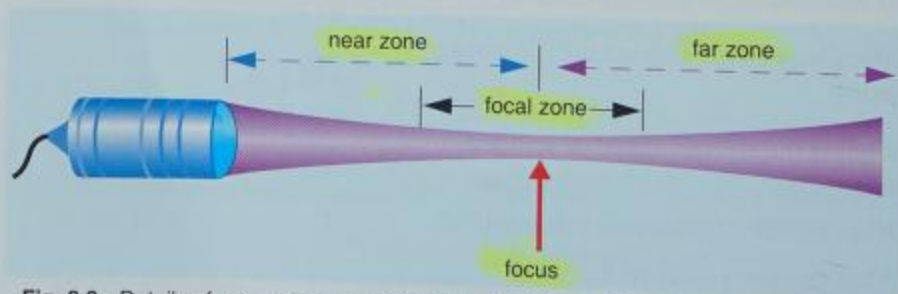


**Fig. 9.2** Details of a sound beam created by an unfocused disc-shaped crystal operating in the continuous mode.

## 1. Focus

The focus, or **focal point**, is the location where the beam is the narrowest (red arrow, Fig. 9.2). For a disc-shaped crystal, the width of the sound beam at the focus is one-half the width of the beam as it leaves the transducer.

## 2. Near Zone

Also called the **near field**, or **Fresnel zone**, the near zone is the region from the transducer to the focus (blue arrow, Fig. 9.2). The beam gradually narrows, or converges, within the near zone.

For a continuous wave, disc-shaped crystal, the diameter of the sound beam as it leaves the transducer is the same as the diameter of the active element. At the end of the near zone, the beam narrows to only one-half the width of the active element. The focus is located at the end of the near zone.

## 3. Focal Length

Also called the **focal depth**, or **near zone length**, the focal length is the distance from the transducer to the focus. Certain characteristics of the active element, discussed later in this chapter, determine the focal length.

**Hint:** The focus can also be described as the focal point, the end of the near zone, the beginning of the far zone, or the middle of the focal zone.

## 4. Far Zone

Also called the **far field** or **Fraunhofer zone**, the far zone is the region that starts at the focus and extends deeper (purple arrow, Fig. 9.2). Within the far zone, the beam diverges, or spreads out.

At the beginning of the far zone, the beam is only one-half as wide as it is at the transducer. From the focus, the beam continues to diverge. When the beam is two near zone lengths from the transducer, the beam is again the same size as the active element. At depths more than two near zone lengths, the beam is wider than the active element.

## 5. Focal Zone

The focal zone is a region around the focus where the beam is relatively narrow (black arrow, Fig. 9.2). Reflections arising from the focal zone create images that are more accurate than those from other depths.

Half of the focal zone is located in the near field, and the other half is located in the far field. You may note that the definition of focal zone is imprecise. Several mathematical descriptions of the focal zone are available but are not essential in this context. The focal zone should simply be understood as a region on either side of the focal point where the beam is relatively narrow, resulting in superior image detail.



## Summary

To clarify the concept of **beam profile**, let us again describe a sound beam:

The sound beam exits the probe and immediately enters the **near or Fresnel zone**. The beam diameter, or width, is exactly the same as that of the transducer. The sound beam gets progressively narrower in the near zone. The beam continues to narrow until it reaches its narrowest point, the **focus**.

The focus marks the end of the near zone. The distance from the transducer to the focus is called the **focal length**, focal depth, or near zone length.

The focus also marks the beginning of the **far or Fraunhofer zone**. At this depth, the sound beam starts to diverge, or widen. The beam continues to widen. At a depth that is twice the focal length, the sound beam is again as wide as the transducer. At depths more than twice the focal length, the beam's width exceeds that of the transducer.

**Table 9.1 Sound Beam Diameters**

| Location                        | Beam Diameter                                   |
|---------------------------------|-------------------------------------------------|
| at the transducer               | beam diameter equals transducer diameter        |
| at the focus                    | beam diameter is one-half transducer diameter   |
| at 2 near zone lengths          | beam diameter equals transducer diameter        |
| deeper than 2 near zone lengths | beam diameter is wider than transducer diameter |

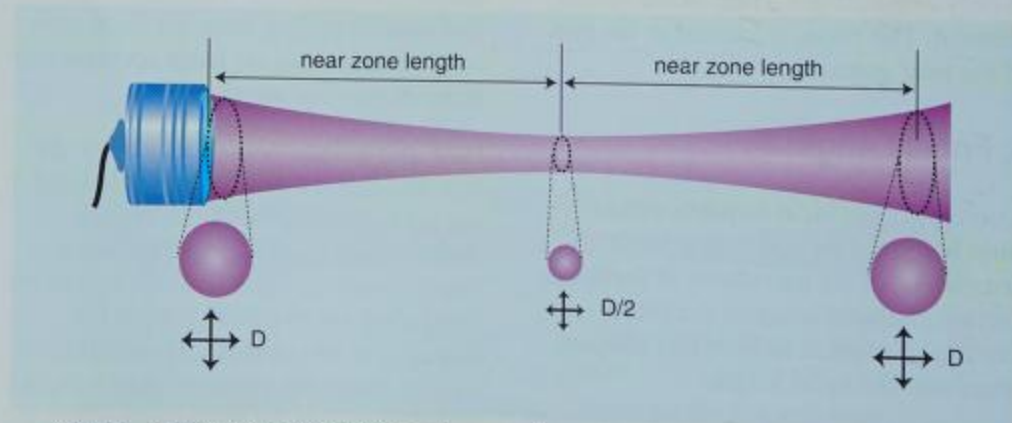


**Fig. 9.3** Upon leaving the transducer, the sound beam's diameter equals the transducer diameter ( $D$ ). At the focal depth, the beam diameter is one-half of the transducer diameter. At two focal depths, the beam diameter returns to that of the transducer.



**Example**

In Fig. 9.4, a disc-shaped PZT crystal creates a continuous wave sound beam. The diameter of the active element is 12 mm, and the near zone length is 8 cm. The focal zone is 4 cm long. Based on this information, answer the following questions:

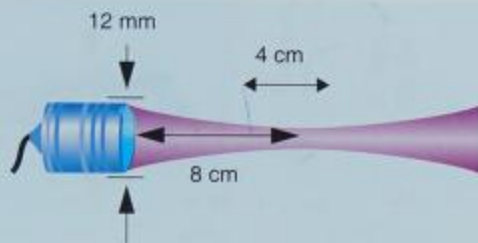
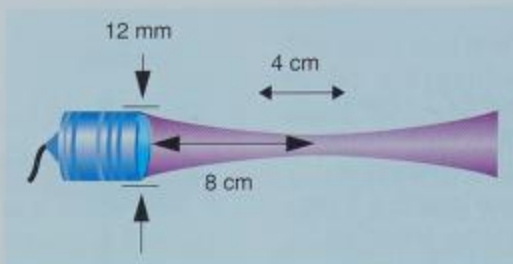


**Fig. 9.4** A disc-shaped PZT crystal creates a continuous sound beam.

| Questions                                                                                                                                                                                | Answers                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 1. What is the best estimate of the diameter or width of the sound beam as it exits the transducer?<br><br>A. 6 mm                      C. 12 mm<br>B. 9 mm                      D. 8 mm | 1. C. At its beginning, the sound beam diameter is the same as the diameter of the active element.                                    |
| 2. What is the diameter of the sound beam at a depth of 8 cm?<br><br>A. 6 mm                      C. 12 mm<br>B. 9 mm                      D. 8 mm                                       | 2. A. At the end of the near zone (which in this example is 8 cm), the beam diameter is one half the transducer diameter.             |
| 3. What is the diameter of the sound beam at a depth of 16 cm?<br><br>A. 6 mm                      C. 12 mm<br>B. 9 mm                      D. 8 mm                                      | 3. C. At a depth equal to 2 near zone lengths, the beam diameter is the same as the diameter of the active element.                   |
| 4. At what depth is the focus?<br><br>A. 6 cm                      C. 1 cm<br>B. 8 cm                      D. 12 mm                                                                      | 4. B. The focal depth is the same as the length of the near zone.                                                                     |
| 5. What depth marks the beginning of the focal zone?<br><br>A. 6 cm                      C. 12 mm<br>B. 8 cm                      D. 8 mm                                                | 5. A. The focal zone is the region around the focus. In this example, the focal zone begins at a depth 2 cm shallower than the focus. |



### Questions

6. What depth marks the end of the focal zone?

- A. 6 cm                      D. 10 cm  
B. 8 cm                      E. 8 mm  
C. 10 mm

7. At which of the following depths is the beam narrowing?

- A. 6 cm                      D. 10 cm  
B. 8 cm                      E. 9 cm  
C. 12 cm

8. At which of the following depths is the beam widening?

- A. 2 cm                      D. 8 cm  
B. 4 cm                      E. 9.375 cm  
C. 6 cm

9. At which of the following depths is the beam most likely to have the same diameter as it has at a depth of 11 cm?

- A. 1 cm                      D. 8 cm  
B. 3 cm                      E. 14 cm  
C. 5 cm

10. Which of the following terms does not belong?

- A. focus  
B. end of the near zone  
C. end of the Fraunhofer zone  
D. middle of the focal zone

### Answers

6. D. The focal zone is the region around the focus. In this example, the focal zone ends at a depth 2 cm deeper than the focus.

7. A. The beam narrows within the near zone. The only depth within the near zone is choice A.

8. E. The beam widens or diverges in the far zone. The only depth within the far zone is choice E.

9. C. Think of the beam as being symmetrical around the focus. Thus, the beam diameter will be similar when it is 3 cm shallower and 3 cm deeper than the focus.

10. C. The end of Fraunhofer zone is the very end of the sound beam.

## Determining Focal Depth

The focal depth (also called the **focal length** or **near zone length**) is the distance from the transducer to the narrowest part of the beam (the focus). Most modern ultrasound systems allow the sonographer to change the location of the focus. Adjustable focus systems are called **phased array**.

However, early in the development of diagnostic ultrasound, the focal depth for each transducer was fixed and the sonographer could not change it. The characteristics of the active element determined the depth of the focus.

### *What characteristics of a fixed focus transducer determine the focal depth?*

With a fixed focus transducer, two factors combine to determine the focal depth:

1. transducer diameter
2. frequency of the sound

### 1. How does transducer diameter affect the focal depth?

A larger diameter results in a deeper focus; therefore, **transducer diameter and focal depth are directly related** (see Fig. 9.5).

For example, the active elements of two probes are identical except that the diameter of one active element is larger than the other. The beam from the larger diameter active element will have a deeper focus.

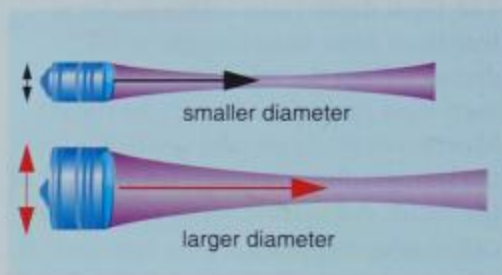


Fig. 9.5 Larger diameter crystals (red arrow) create beams with deeper foci.

### 2. How does frequency affect focal depth?

Higher frequency sound results in a deeper focus; therefore, **frequency and focal depth are directly related** (see Fig. 9.6).

For example, consider two identical transducers, except that one emits sound at 8 MHz and the other emits sound at 4 MHz. The 8 MHz beam will have a deeper focus than the 4 MHz beam.

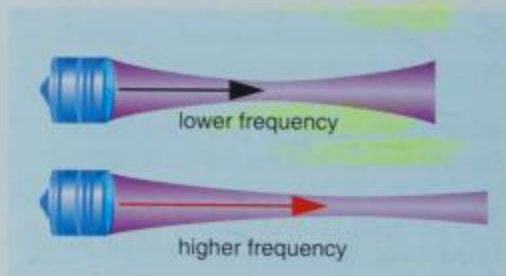


Fig. 9.6 Higher frequency sound (red arrow) creates beams with deeper foci.

Table 9.2 Factors that Affect Focal Depth

| Shallow Focus          | Deep Focus            |
|------------------------|-----------------------|
| • smaller diameter PZT | • larger diameter PZT |
| • lower frequency      | • higher frequency    |



## A Clinical Dilemma

The fact that higher frequency sound creates a deeper focus is particularly troublesome to sonographers.

Sonographers often incorrectly think, “How can this be? Since high frequency transducers are used to image superficially, high frequency beams should have a shallow focus.” This is not the case and the explanation for this follows:

The rule of physics is: **higher frequency sound creates a deeper focus.**

Transducer manufacturers are aware of this “bad physics” and overcome it by making **very small diameter, high frequency crystals.**

Even with high frequency sound, an extremely small diameter displaces the focus shallower. This combination creates a clinically useful transducer.

In soft tissue, the equation that describes the mathematical relationship between diameter, frequency, and focal depth is as follows:

**Note:** Formal mathematical equations are not particularly important for the board exams. It is important to understand the concepts.

$$\text{focal depth (mm)} = \frac{\text{diameter (mm)}^2 \times \text{frequency (MHz)}}{6}$$

Another way to report this relationship is

$$\text{focal depth (mm)} = \frac{\text{diameter (mm)}^2}{4 \times \text{wavelength (mm)}}$$

| Questions                                                                                                                                                                                                                    | Answers                                                                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. A pair of 6 MHz probes are identical except for the active element diameter. The active element diameters are 6 mm and 10 mm, respectively. The sound beam of which probe will have a shallower focus?                    | 1. The probe with a 6 mm active element has a shallower focus. Smaller diameter crystals produce beams with shallower foci.                                                                                 |
| 2. A pair of 9 mm diameter probes are identical except for frequency, which is 3 MHz and 6 MHz, respectively. Which beam will have a shallower focus?                                                                        | 2. The 3 MHz beam has a shallower focus. Focal depth increases with increasing frequency. The beam created by the 6 MHz probe has a deeper focus.                                                           |
| 3. Which of the following probes creates a beam with the deepest focus?<br>A. 4 mm diameter, 4 MHz<br>B. 6 mm diameter, 8 MHz<br>C. 6 mm diameter, 2 MHz<br>D. 5 mm diameter, 8 MHz                                          | 3. B. Longer focal lengths are associated with large diameter, high frequency probes. The probe identified as choice B has the largest diameter and highest frequency and, therefore, the deepest focus.    |
| 4. Which of the following probes creates a beam with the shallowest focus?<br>A. 4 mm diameter, 4 MHz<br>B. 6 mm diameter, 8 MHz<br>C. 4 mm diameter, 2 MHz<br>D. 5 mm diameter, 8 MHz                                       | 4. C. Shorter focal lengths are associated with small diameter, low frequency probes. The probe identified as choice C has the smallest diameter and lowest frequency and, therefore, the shallowest focus. |
| 5. Which of the following probes creates a beam with the shallowest focus?<br>A. small diameter, high frequency<br>B. large diameter, high frequency<br>C. small diameter, low frequency<br>D. large diameter, low frequency | 5. C. Shorter focal lengths are associated with small diameter, low frequency probes.                                                                                                                       |
| 6. True or False. Active element diameter and near zone length are directly related.                                                                                                                                         | 6. True. Diameter and near zone length are directly related.                                                                                                                                                |
| 7. True or False. Transducer frequency and near zone length are inversely related.                                                                                                                                           | 7. False. Frequency and near zone length are directly related.                                                                                                                                              |
| 8. True or False. Wavelength and near zone length are inversely related.                                                                                                                                                     | 8. True. Wavelength and near zone length are inversely related.                                                                                                                                             |

## Sound Beam Divergence

The diameter of a sound beam is smallest at the end of the near zone, the focus. Deeper than the focus, the sound beam spreads out, or diverges. **Beam divergence** describes the gradual spread of the ultrasound beam in the far field.

*What characteristics of a transducer determine the spread of the beam in the far field?*

Two factors combine to determine beam divergence:

1. transducer diameter
2. frequency of the sound

*1. How does transducer diameter affect beam divergence in the far field?*

Smaller diameter crystals produce beams that spread out or diverge more in the deep far (Fraunhofer) zone. That is, **crystal diameter and beam divergence are inversely related.**

Smaller diameter crystals produce beams that spread out more in the far field (black arrow, Fig. 9.7). Larger diameter crystals produce beams that diverge less in the far field (red arrow, Fig. 9.7).

Since larger diameter crystals create sound beams that diverge less in the far field, **larger diameter crystals improve lateral resolution in the far field.**

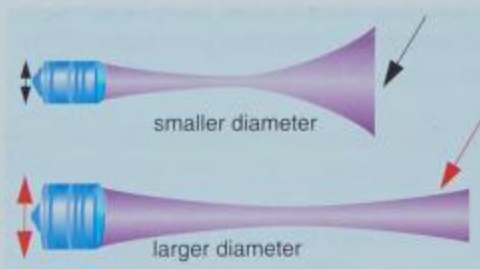


**Fig. 9.7** Smaller diameter crystals create more divergent beams, black arrow. Larger diameter crystals create less divergent (narrower) sound beams in the far field, red arrow. Both transducers have the same frequency.



## 2. How does frequency alter beam divergence in the far field?

Lower frequency sound beams spread out or diverge more in the deep far (Fraunhofer) zone. That is, **frequency and beam divergence are inversely related** (see Fig. 9.8).

Since high frequency sound beams diverge less in the far field, higher frequency sound **improves lateral resolution in the far field**.

For example, two transducers are identical except for different frequencies, 8 MHz and 4 MHz. The 8 MHz sound beam will diverge less. Thus, in the far zone, higher frequencies result in smaller beam diameters.

The mathematical relationship which describes the effect of transducer diameter and frequency on beam divergence is:

$$\sin \text{ divergence angle} = \frac{1.85}{\text{diameter (mm)} \times \text{frequency (MHz)}}$$

Another way to report this is:

$$\sin \text{ divergence angle} = \frac{1.2 \times \text{wavelength}}{\text{diameter}}$$

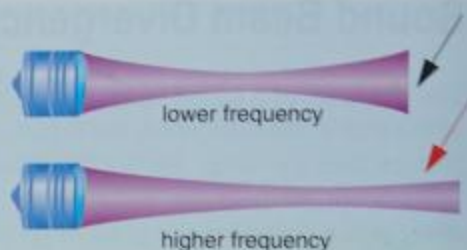


**Fig. 9.8** Lower frequency sound creates more divergent beams, black arrow. Higher frequency sound creates less divergent (narrower) sound beams, red arrow. Both transducers have the same diameter.

**Table 9.3** Factors that Affect Beam Divergence in the Far Field

| Less Divergence    | More Divergence    |
|--------------------|--------------------|
| • larger diameter  | • smaller diameter |
| • higher frequency | • lower frequency  |

**Note:** The formal math is not particularly important, but be sure to know that larger transducer diameters produce a beam with less divergence. Similarly, higher frequency sound produces a beam with less divergence.



| Questions                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. A pair of 6 MHz probes are identical except for the active element diameters, which are 6 mm and 10 mm, respectively. Which beam will be more compact in the far field?                                                  | 1. The probe with a 10 mm active element has a less divergent beam. Larger diameter crystals produce beams that diverge less in the far field.                                                                       |
| 2. A pair of 9 mm diameter probes are identical except for frequencies, which are 3 MHz and 6 MHz. Which sound beam will spread out more in the far field?                                                                  | 2. The 3 MHz beam is more divergent. Beams are more compact as frequency increases. The 6 MHz beam will diverge less, whereas the 3 MHz beam will diverge more.                                                      |
| 3. Which of the following probes creates a beam with the least divergence?<br>A. 4 mm diameter, 4 MHz<br>B. 6 mm diameter, 8 MHz<br>C. 6 mm diameter, 2 MHz<br>D. 5 mm diameter, 8 MHz                                      | 3. B. Divergence is minimized with large diameter, high frequency probes. The probe identified as choice B has the largest diameter and highest frequency. Therefore, it has the most compact, least divergent beam. |
| 4. Which of the following probes creates a beam with the most divergence?<br>A. 4 mm diameter, 4 MHz<br>B. 6 mm diameter, 8 MHz<br>C. 4 mm diameter, 2 MHz<br>D. 5 mm diameter, 8 MHz                                       | 4. C. Divergence is pronounced with small diameter, low frequency probes. The probe identified as choice C has the smallest diameter and lowest frequency. Therefore, it has the least compact, most divergent beam. |
| 5. Which of the following probes creates a beam with the most divergence?<br>A. small diameter, high frequency<br>B. large diameter, high frequency<br>C. small diameter, low frequency<br>D. large diameter, low frequency | 5. C. Divergence is pronounced with small diameter, low frequency probes.                                                                                                                                            |
| 6. True or False. Transducer frequency and beam divergence are inversely related.                                                                                                                                           | 6. True. Higher frequencies create less divergent beams.                                                                                                                                                             |
| 7. True or False. Active element diameter and beam divergence are inversely related.                                                                                                                                        | 7. True. Crystals with larger diameters create less divergent beams.                                                                                                                                                 |

## Spherical Waves

Sound waves produced by very small sources (tiny pieces of PZT) diverge in the shape of a “V” (see Fig. 9.9). The V-shaped wave is created when the source is about the size of the sound’s wavelength.

These V-shaped waves are known as **spherical waves, diffraction patterns, or Huygens’ wavelets**. The small sources of sound producing these wavelets are known as **Huygens’ sources**.

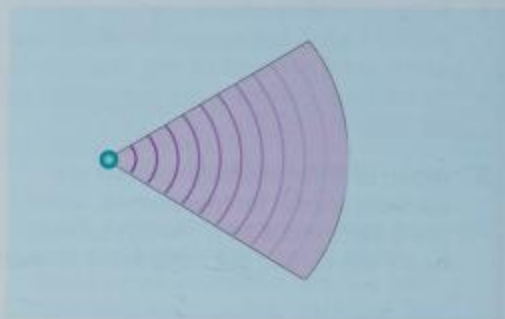


**Fig. 9.9** Tiny pieces of PZT create V-shaped waves. These are also called spherical waves or Huygens’ wavelets.

## Huygens’ Principle

We have previously learned that ultrasound transducers with large PZT crystals create sound beams that are shaped like an hourglass (see page 130). However, small sound sources create beams that are V-shaped. This apparent inconsistency between large and small sound sources and their beams was explained by Christiaan Huygens and is known as **Huygens’ Principle**.

Huygens’ Principle states that a large active element may be thought of as millions of tiny, distinct sound sources. Each of these tiny particles is a Huygens’ source and creates a Huygens’ wavelet with a V-shape.

The hourglass shape produced by a large crystal is the result of interference of the many Huygens' sound wavelets emitted from these numerous sound sources (see Fig. 9.10). Some of these wavelets are in-phase and interfere constructively, creating an hourglass-shaped sound beam. Destructive interference occurs where the wavelets are out-of-phase and the sound beam is cancelled.

Thus, Huygens' Principle explains the shape of an imaging transducer's emitted sound beam based upon in-phase and out-of-phase wavelets interfering with each other.

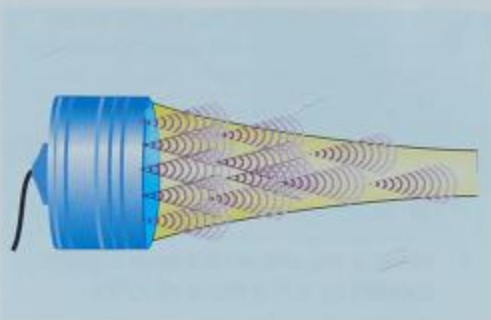


**Fig. 9.10** Many small particles in the disc-shaped crystal create individual Huygens' wavelets. They interfere, creating an hourglass-shaped beam.

## Review: Sound Beams

| Questions                                                                                                                                                         | Answers       |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| 1. The frequency of a transducer does not change. If the diameter of the new piezoelectric crystal increases, what happens to the near zone length?               | 1. increases. |
| 2. The frequency of a transducer does not change. If the diameter of the new piezoelectric crystal increases, what happens to the beam diameter in the far zone?  | 2. decreases. |
| 3. The frequency of a transducer does not change. If the diameter of the new piezoelectric crystal increases, what happens to the wavelength?                     | 3. no change. |
| 4. The frequency of a transducer does not change. If the diameter of the new piezoelectric crystal increases, what happens to the beam diameter in the near zone? | 4. increases. |



| Questions                                                                                                                                                                                                                                           | Answers                                                                                                                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 5. At what location is the sound beam diameter three times greater than the transducer diameter?<br>A. at the end of the near zone<br>B. at a depth equal to four focal lengths<br>C. at the end of the far zone<br>D. at the triple-diameter depth | 5. B. The only region where the beam diameter exceeds the transducer diameter is at depths exceeding two focal lengths.                 |
| 6. What is the shape of a sound beam created by a tiny piece of PZT?<br>A. hourglass shaped<br>B. V-shaped<br>C. round<br>D. shaped like a tube                                                                                                     | 6. B. A small piece of PZT creates a sound beam that is V-shaped. This wave is also called a diffraction pattern or a Huygens' wavelet. |
| 7. Which of the following explains why a sound beam created by a disc-shaped crystal is hourglass shaped?<br>A. Bernoulli's Principle<br>B. Sheffield's Law<br>C. Ohm's Law<br>D. Huygens' Principle                                                | 7. D. Huygens' Principle.                                                                                                               |
| 8. Which of the following locations is the deepest?<br>A. end of the Fresnel zone<br>B. end of the focal zone<br>C. end of the Fraunhofer zone<br>D. end of the near zone                                                                           | 8. C. The end of the Fraunhofer zone identifies the deepest part of a sound beam.                                                       |
| 9. Which of the following locations is the most shallow?<br>A. beginning of the far zone<br>B. beginning of the focal zone<br>C. focal depth<br>D. beginning of the Fraunhofer zone                                                                 | 9. B. Of these choices, the beginning of the focal zone is the most shallow.                                                            |



# Axial and Lateral Resolution

**Resolution** is the ability to create accurate images. Image accuracy is the essence of diagnostic ultrasound. There are many ways to describe image accuracy, and thus, different forms of resolution.

## Axial Resolution

### Axial resolution

Axial resolution describes one measure of the detail found in an image. It measures the ability of a system to display two structures that are very close together when the structures are **parallel to the sound beam's main axis**. The reflectors are positioned one in front of the other (see Fig. 10.1).

Axial resolution answers the question: *what is the minimum distance that two structures, positioned front-to-back (or parallel to the sound beam) can be apart and still produce two distinct echoes on an ultrasound image?*

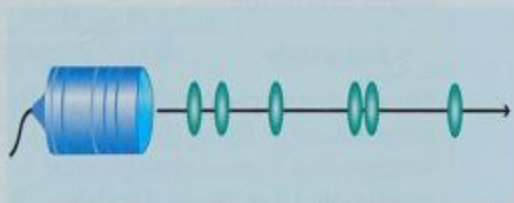


**Fig. 10.1** Axial resolution deals with structures that are parallel to the sound beam.

**Units**

Axial resolution is measured in mm or any other unit of distance.

**Determined By**

Axial resolution is related to the **spatial pulse length**. Recall that spatial pulse length is determined by both the sound source and the medium.

Shorter pulses improve axial resolution (see Fig. 10.2).

Axial resolution is also related to pulse duration. In a particular medium, short duration pulses also have a short length.

**Synonyms**

Axial resolution is also called **longitudinal, range, radial** or **depth resolution**.

**Adjustable**

No. Since the spatial pulse length for a transducer is fixed, the sonographer cannot change axial resolution. (See "Spatial Pulse Length" on page 51.)

**Typical Values**

In clinical imaging, axial resolution ranges from 0.1 to 1.0 mm. Lower numerical values indicate shorter pulses and improved image accuracy.



**Fig. 10.2** The black dots indicate actual reflectors. The red pulse is shorter than the green pulse. Two closely spaced reflectors are accurately imaged with the red pulse but not with the longer green pulse.

**Hint:** For axial resolution, use the mnemonic **LARRD**:

- Longitudinal
- Axial
- Range
- Radial
- Depth

## More About Axial Resolution

*What is the relationship between the numerical value of the axial resolution and the image quality?*

Lower numerical values of axial resolution indicate a shorter pulse. Shorter pulses create more accurate images; therefore, the image quality is better when axial resolution has a lower numerical value. The mathematical description of axial resolution is:

$$\text{axial resolution (mm)} = \frac{\text{spatial pulse length (mm)}}{2}$$

$$\text{axial resolution (mm)} = \frac{\text{wavelength (mm)} \times \# \text{ cycles in pulse}}{2}$$

In soft tissue:

$$\text{axial resolution (mm)} = \frac{0.77 \times \# \text{ cycles in pulse}}{\text{frequency (MHz)}}$$

*What allows some transducers to have better axial resolution than others?*

Axial resolution is determined by the pulse length, with shorter pulses yielding improved axial resolution.

A short pulse is created in two ways:

1. less ringing
2. higher frequency

### 1. Less Ringing

A pulse is short if there are few cycles in the pulse, just like a train is short if there are few cars in the train. This is known as **less ringing** (see Fig. 10.3).

Transducer designers have developed techniques to create pulses that comprise only 2 or 3 cycles. One way to reduce ringing is to dampen the crystal after it has been excited by an electrical signal from the system.

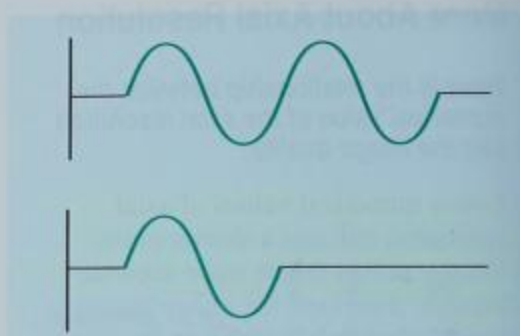


**Fig. 10.3** The lower pulse is shorter because it contains only 1 cycle. The lower pulse rings less than the upper pulse.

### 2. Higher Frequency

A pulse is short if each cycle in the pulse has a short wavelength, just like a train is short if each car in the train is short. Shorter wavelengths are characteristic of higher frequency sound. Pulses made of higher frequency cycles have superior axial resolution (see Fig. 10.4).

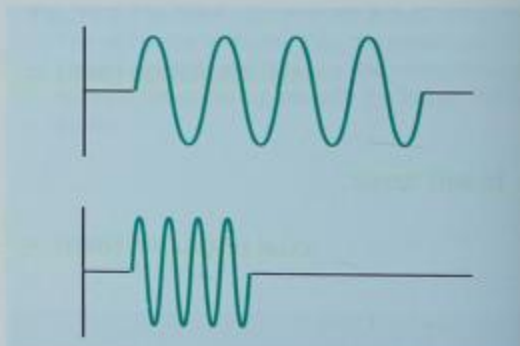


**Fig. 10.4** Even though both pulses contain four cycles, the lower pulse is shorter because it contains higher frequency sound. Higher frequency sound has shorter wavelengths and better axial resolution.

**Table 10.1 Improved Axial Resolution**

**Better axial resolution is associated with the following:**

- shorter spatial pulse length
- shorter pulse duration
- higher frequencies (shorter wavelength)
- fewer cycles per pulse (less ringing)
- lower numerical values



## Review: Axial Resolution

| Questions                                                                                                                                                                                                   | Answers                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 1. What is the ability to accurately distinguish two structures lying close together called?                                                                                                                | 1. resolution.                                                                                                                           |
| 2. The ability to distinguish two structures lying close together front-to-back or parallel to the sound beam is called _____.                                                                              | 2. longitudinal, axial, range, radial, or depth resolution.                                                                              |
| 3. Axial resolution is measured with units of _____.                                                                                                                                                        | 3. distance, such as mm.                                                                                                                 |
| 4. If there are more cycles in a pulse, the numerical value of range resolution is [greater, lesser, same].                                                                                                 | 4. greater.                                                                                                                              |
| 5. If a new pulsed transducer has many more cycles in its pulse, the image accuracy _____ [improves, degrades, remains the same].                                                                           | 5. degrades.                                                                                                                             |
| 6. [High, Low] frequency transducers generally have the best range resolution.                                                                                                                              | 6. High.                                                                                                                                 |
| 7. Which of the following transducers has the poorest axial resolution?<br>A. 1.7 MHz and 4 cycles/pulse<br>B. 2.6 MHz and 3 cycles/pulse<br>C. 1.7 MHz and 5 cycles/pulse<br>D. 2.6 MHz and 2 cycles/pulse | 7. C. This is the longest pulse. It has the lowest frequency and the most ringing (more cycles/pulse).                                   |
| 8. In soft tissue, a 3 cycle, 1 MHz pulse has a pulse length equal to 4.5 mm. What is the axial resolution?<br>A. 3 mm<br>B. 1 mm<br>C. 2.25 mm<br>D. 1.54 mm                                               | 8. C. In this setting, the axial resolution is 2.25 mm. Axial resolution is one-half of the spatial pulse length (4.5 mm / 2 = 2.25 mm). |

| Questions                                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>9. Which of the following transducers has the best axial resolution?</p> <p>A. 1.7 MHz and 4 cycles/pulse<br/>           B. 2.6 MHz and 3 cycles/pulse<br/>           C. 1.7 MHz and 5 cycles/pulse<br/>           D. 2.6 MHz and 2 cycles/pulse</p>                                                                                                          | <p>9. D. This is the shortest pulse. It has the highest frequency and the least ringing (fewest cycles/pulse).</p>                                                                                                                                                                                                                                                                                                                                                  |
| <p>10. Two different transducers create sound pulses. One transducer is labeled 5 MHz and the other, 3 MHz. Which transducer is more likely to create a more accurate image with respect to axial resolution? Which transducer probably has a lower numerical value of axial resolution?</p>                                                                     | <p>10. The 5 MHz transducer is more likely to create an image with better axial resolution.</p> <p>The higher frequency transducer creates a shorter pulse and thus has a lower numerical value of axial resolution. Lower numbers mean improved image quality.</p>                                                                                                                                                                                                 |
| <p>11. Two different transducers create pulses. Both transducers create sound with a frequency of 4 MHz. One transducer creates a pulse that comprises 6 cycles and the other, 3 cycles. Which transducer is more likely to create a more accurate image with respect to axial resolution? Which transducer has a lower numerical value of axial resolution?</p> | <p>11. The 3-cycle pulse transducer is more likely to create an image with better axial resolution. Less ringing, or fewer cycles in a pulse, generally implies shorter pulses and improved axial resolution.</p> <p>The 3-cycle pulse has a lower numerical value of axial resolution. Lower numbers mean improved image accuracy.</p>                                                                                                                             |
| <p>12. Two different transducers create pulses. One transducer is labeled 5 MHz and the other, 3 MHz. The 3 MHz transducer creates a more accurate image with respect to axial resolution. Explain.</p>                                                                                                                                                          | <p>12. Axial resolution is determined by pulse length. Shorter pulses have better axial resolution. In this question, the 3 MHz transducer has the best axial resolution, which means the 3 MHz pulse must be shorter than the 5 MHz pulse.</p> <p>Since 3 MHz sound has a longer wavelength than 5 MHz sound, the only way that the 3 MHz pulse is shorter is if the 3 MHz transducer rings less. Thus, the 3 MHz pulse has fewer cycles than the 5 MHz pulse.</p> |

## Lateral Resolution

Image accuracy is critically important in diagnostic ultrasound. **Resolution** refers to accuracy in imaging. In addition to axial resolution, lateral resolution also measures detail in an image.

### Lateral Resolution

Lateral resolution is the ability to distinctly identify two structures that are very close together when they are **side by side**, or **perpendicular**, to the sound beam's main axis.

Lateral resolution answers the question: *what is the minimum distance that two structures, positioned side by side, can be apart and still produce two distinct echoes on an ultrasound image?*

### Units

Lateral resolution is measured in units of mm, cm, or any unit of distance. Smaller numbers are preferable since they indicate more accurate images.

### Determined By

Lateral resolution is determined by the **width of the sound beam**; narrower beams have better resolution.

Beam diameter varies with depth; lateral resolution changes with depth.

### Synonyms

Lateral resolution is also called *angular*, *transverse*, or *azimuthal resolution*.

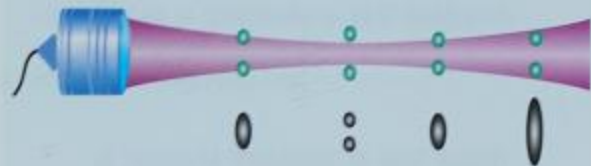


**Fig. 10.5** Lateral resolution relates to structures that are positioned perpendicular to the sound beam. The green objects represent actual reflectors along the path of the sound beam. The black ovals represent the reflections appearing on an image.

**Hint:** For lateral resolution, use the mnemonic LATA:

Lateral  
Angular  
Transverse  
Azimuthal



## More About Lateral Resolution

Lateral resolution is best at the focus (at the end of the near zone) where the beam is narrowest. Lateral resolution is good within the focal zone (see Fig. 10.6).

The mathematical relationship that describes this relationship is as follows:

$$\text{lateral resolution (mm)} = \text{beam diameter (mm)}$$

***Which type of resolution is better in clinical imaging systems: lateral resolution or axial resolution?***

In clinical situations, axial resolution is better than lateral resolution because ultrasound pulses are shorter than they are wide. Thus, the numerical value for axial resolution is less than the value for lateral resolution.

***What appears on an image when two reflectors positioned perpendicular to the sound beam are closer to each other than the beam width?***

When two side-by-side reflectors are closer to each other than the width of the beam, only one reflection is observed on the image. In Fig. 10.7, lateral resolution is suboptimal at the red arrows.

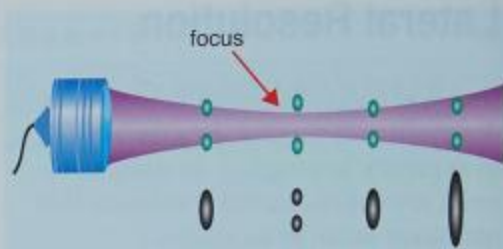


**Fig. 10.6** Lateral resolution is best at the focus, where the beam is the narrowest. Lateral resolution changes with depth.

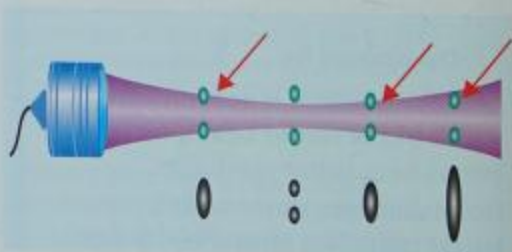


**Fig. 10.7** When two structures are closer together than the beam's diameter, only one reflection is seen on the image (black ovals).



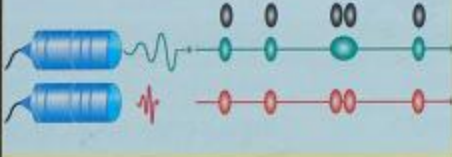
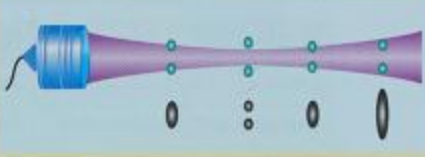
*With regard to resolution, what are the advantages of using a high frequency transducer?*

Higher frequencies improve both axial and lateral resolution.

**Axial resolution** is improved in the entire image because shorter pulses are associated with high frequency sound.

**Lateral resolution** is improved in the far field only because high frequency pulses diverge less in the far field than low frequency pulses. Higher frequency sound beams are narrower than lower frequency beams.

Table 10.2 Comparison of Axial and Lateral Resolution

|                                     | Axial                                                                             | Lateral                                                                            |
|-------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
|                                     |  |  |
| <b>Orientation</b>                  | front-to-back<br>parallel to beam                                                 | side-by-side<br>perpendicular to beam                                              |
| <b>Mnemonic</b>                     | LARRD                                                                             | LATA                                                                               |
| <b>Determined by</b>                | pulse length                                                                      | beam width                                                                         |
| <b>Best with:</b>                   | shortest pulse<br>highest frequency and fewest cycles                             | narrowest beam                                                                     |
| <b>Does It Change?</b>              | same at all depths,<br>does not change                                            | changes with depth,<br>best at focus                                               |
| <b>In Near Field,<br/>best with</b> | shortest pulse                                                                    | smallest diameter crystal                                                          |
| <b>In Far Field,<br/>best with</b>  | shortest pulse                                                                    | largest diameter & highest frequency<br>(least divergence)                         |

## Focusing

Focusing concentrates the sound energy into a narrower beam and thus improves lateral resolution.

The three methods of focusing are:

1. **external focusing**—with a lens
2. **internal focusing**—with a curved active element
3. **phased array focusing**—with the electronics of the ultrasound system

Internal and external focusing may be used with single element transducers. Phased array focusing is reserved specifically for array transducers—those with multiple active elements.

Table 10.3 Focusing Techniques

| Method                | Name         | Type                               |
|-----------------------|--------------|------------------------------------|
| Lens                  | external     | fixed, conventional, or mechanical |
| Curved active element | internal     | fixed, conventional, or mechanical |
| Electronic            | phased array | adjustable                         |

### Fixed Focusing Techniques

**Fixed focusing**, also called conventional or mechanical focusing, includes both external and internal techniques. With fixed focusing, the focal depth and the extent of focusing are determined when the transducer is fabricated, and cannot be changed.

## 1. External Focusing: The Lens

With external focusing, a **lens** is placed in front of the piezoelectric material. In Fig. 10.8, the lens appears as the red structure and the PZT is green. Focusing sound waves with this acoustic lens is similar to focusing light waves with a lens, such as with eyeglasses. This is a fixed-focusing technique.

As the arc of the lens becomes more prominent, the degree of focusing increases and the beam narrows in the focal zone.

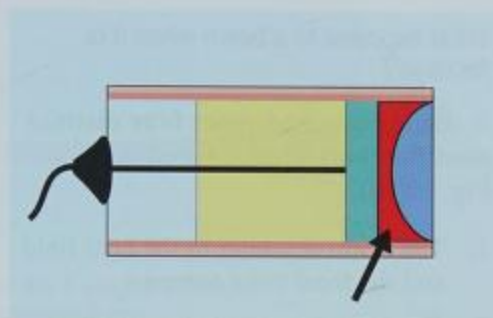


**Fig. 10.8** Focusing with an acoustic lens (red) is an example of external focusing.

## 2. Internal Focusing: Curvature of PZT

With internal focusing, a **curved piezoelectric crystal** concentrates the sound energy into a narrower or tighter beam. As the curvature of the PZT becomes more pronounced, the degree of focusing increases. Internal focusing is the most common form of fixed focusing. In Fig. 10.9, the curved PZT crystal is in green. There is no lens with internal focusing.

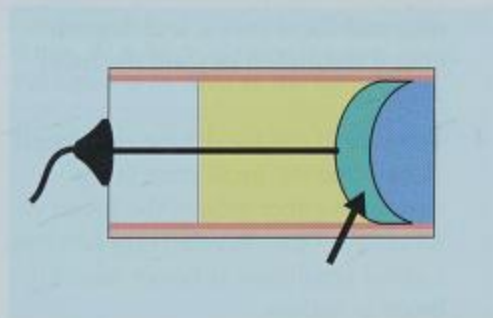


**Fig. 10.9** Internal focusing is achieved with a curved PZT crystal (green).

## 3. Electronic Focusing: Phased Array

In **phased array transducers**, the system's **electronics focus the sound beam**. With phased arrays, the sonographer can adjust the focusing characteristics of a beam. This technique may be used only on multi-element transducers, never on single crystal transducers.

Phased array technology (see “Linear Phased Arrays” on page 169) is more versatile than fixed focusing techniques.

**Note:** Phased array means adjustable or multiple focusing.



## More About Focusing

*What happens to a beam when it is focused?*

A sound beam undergoes **four distinct modifications** when focused (see Fig. 10.10):

1. The beam diameter in the near field and the focal zone narrows.
2. The focus is moved closer to the transducer. In other words, the near zone length is reduced.
3. The beam diameter beyond the focal zone widens. Therefore, focusing improves lateral resolution in the near and focal zones, and degrades lateral resolution beyond the focal zone.
4. The size of the focal zone is reduced. Recall that the focal zone is the region on either side of the focus where the beam is relatively narrow. Lateral resolution is better where the beam is narrow.

Table 10.4 Four Focusing Effects

| Effects of Focusing                                     |
|---------------------------------------------------------|
| • beam diameter in near field and focal zone is reduced |
| • focal depth is shallower                              |
| • beam diameter in the far zone increases               |
| • focal zone is smaller                                 |

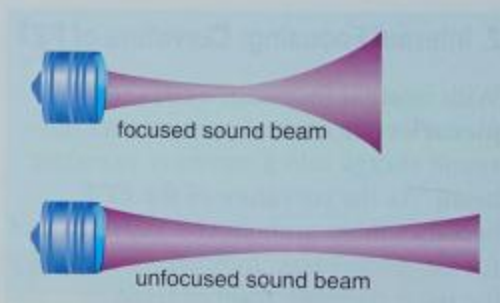


Fig. 10.10 Effects of focusing. The upper beam is focused. The lower beam is unfocused.

## Summary of Beam Features

Table 10.5 Determinants of Sound Beams

| Characteristics           | Determined by                                             |
|---------------------------|-----------------------------------------------------------|
| Frequency—Continuous Wave | frequency of electrical signal from ultrasound system     |
| Frequency—Pulsed Wave     | thickness of ceramic <i>and</i> speed of sound in ceramic |
| Focal Length              | diameter of ceramic <i>and</i> frequency of sound         |
| Beam Divergence           | diameter of ceramic <i>and</i> frequency of sound         |
| Lateral Resolution        | beam width                                                |



## Review: Lateral Resolution

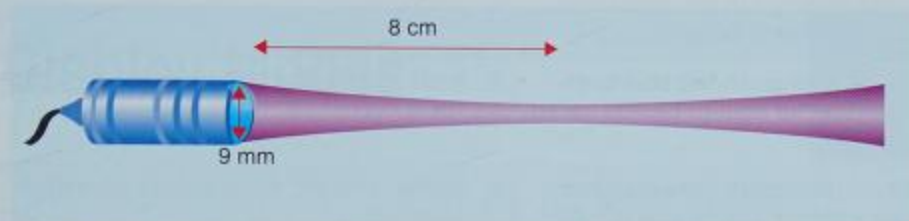


**Fig. 10.11** Use this image and information to answer the 5 questions below.  
The near zone length is 8 cm. The transducer diameter is 9 mm.

| Questions                                                                                              | Answers                                                                                        |
|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| 1. What is the lateral resolution at a depth of 8 cm?                                                  | 1. 4.5 mm. At the end of the near zone, the beam diameter is one half the transducer diameter. |
| 2. What is the lateral resolution at a depth of 16 cm?                                                 | 2. 9 mm. At a depth of twice the near zone, the beam is as wide as the transducer.             |
| 3. What is the best estimate for the resolution at 4 cm?<br>A. 1 cm<br>B. 9 mm<br>C. 5 mm<br>D. 14 mm  | 3. C.                                                                                          |
| 4. What is the best estimate for the resolution at 7 cm?<br>A. 1 cm<br>B. 9 mm<br>C. 5 mm<br>D. 14 mm  | 4. C.                                                                                          |
| 5. What is the best estimate for the resolution at 21 cm?<br>A. 1 cm<br>B. 9 mm<br>C. 5 mm<br>D. 14 mm | 5. D.                                                                                          |

| Questions                                                                                                                                                                                                                                          | Answers                                                                                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| 6. The ability to distinguish two structures lying close together is called _____.                                                                                                                                                                 | 6. resolution.                                                                                                               |
| 7. The ability to distinguish two structures lying close together front-to-back is called _____.                                                                                                                                                   | 7. axial, longitudinal, range, radial, or depth resolution.                                                                  |
| 8. The ability to distinguish two structures lying close together side by side is called _____.                                                                                                                                                    | 8. lateral, angular, transverse or azimuthal resolution.                                                                     |
| 9. Axial resolution and lateral resolution are both measured with units of _____.                                                                                                                                                                  | 9. distance, such as mm.                                                                                                     |
| 10. When the number of cycles in a pulse increases while the frequency remains the same, the numerical value of the range resolution [increases, decreases, remains the same].                                                                     | 10. Increases. With more cycles in a pulse, the pulse becomes longer. The numerical value of the range resolution increases. |
| 11. When the number of cycles in a pulse increases (more ringing) while the frequency remains the same, the image quality [improves, degrades, remains the same].                                                                                  | 11. Degrades. When the number of cycles increases, the spatial pulse length increases and the image quality degrades.        |
| 12. [High, Low] frequency transducers have the best range resolution.                                                                                                                                                                              | 12. High frequency.                                                                                                          |
| 13. Name the 4 synonyms for axial resolution.                                                                                                                                                                                                      | 13. longitudinal, axial, range, radial, and depth (mnemonic: LARRD).                                                         |
| 14. Name the 3 synonyms for lateral resolution.                                                                                                                                                                                                    | 14. lateral, angular, transverse, and azimuthal (mnemonic: LATA).                                                            |
| 15. The length of a pulse is 8 mm. What is the minimum distance between two reflectors, positioned one in front of the other, that still produces two echoes on our image?<br>A. 8 mm<br>B. 4 mm<br>C. 16 mm<br>D. 2 mm<br>E. cannot be determined | 15. B. 4 mm: This value is one-half the pulse length.                                                                        |

# Display Modes

Three basic modes of display, or **formats**, of viewing ultrasound information have significance:

1. Amplitude mode
2. Brightness mode
3. Motion mode

## 1. A-mode—Amplitude

A-mode appears as a series of upward spikes (see Fig. 11.1). A-mode displays are created as follows:

- As a sound pulse is emitted by the transducer, a dot moves at a constant speed across the system's display.
- When a reflection returns to the transducer, it is processed and the moving dot is deflected upward on the screen.

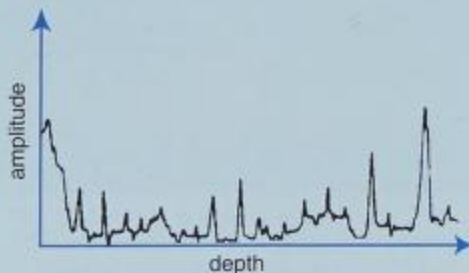


**Fig. 11.1** Diagram of an A-mode display. The horizontal, or x-axis, represents reflector depth. The vertical, or y-axis, represents signal strength, or amplitude, of the reflected signal.

The height of the upward deflection is proportional to the amplitude of the returning echo; hence, the name **amplitude mode**. Strong echoes create tall spikes, whereas weak reflections create short spikes (see Fig. 11.2).

The **x-axis** (horizontal) of an A-mode display represents reflector **depth**, which is derived from the time-of-flight information of the sound pulse.

The **y-axis** (vertical) represents reflection **amplitude**.

A-mode is accurate in determining the **depth of reflectors**. This feature is used extensively in **ophthalmology**, where accurate measurements of depth or structure thickness are important (see Fig. 11.3).

**Note:** An A-mode display looks like a big city skyline.

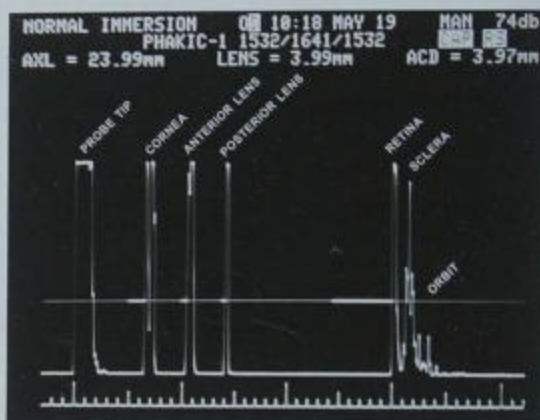


Fig. 11.2 Actual A-mode display. Boundaries create reflections and correspond with upward deflection on the display. Source: Cynthia Kendall.

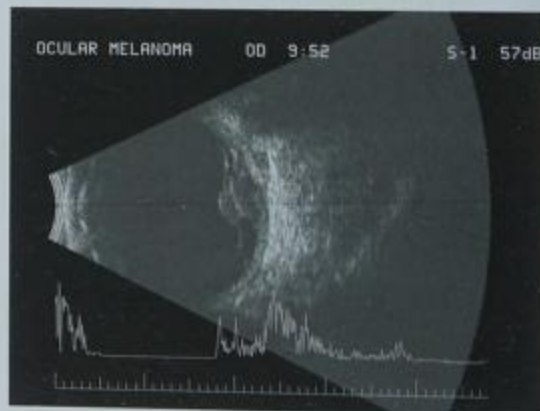


Fig. 11.3 Actual A-mode superimposed upon a 2-dimensional image of the eye. Note that the reflectors on the gray scale image correspond to the spikes of the A-mode. Source: Cynthia Kendall.



## 2. B-mode—Brightness

B-mode appears as a line of dots of varying brightness. B-mode displays are created as follows:

- As a sound pulse is emitted by the transducer, an **invisible dot** moves at a constant speed across the system's display.
- When a reflection returns to the transducer, it is processed and the invisible dot is turned on (see Fig. 11.4).

The brightness of the dot indicates the strength of the reflection; hence, the name **brightness mode**. Weaker reflections appear as darker gray dots, whereas stronger reflections appear as brighter white dots.

The **x-axis** of a B-mode represents reflector **depth**, which is derived from the time-of-flight information of the sound pulse (see Fig. 11.4).

When displayed on an oscilloscope, the **amplitude** information of a B-mode is routed into the **z-axis**.

B-mode, which was the first form of gray scale imaging, is the basis for all other types of gray scale imaging (see Fig. 11.5), including real-time imaging.

**Note:** Some authors use the terms B-mode or B-scan to describe any form of gray scale image.

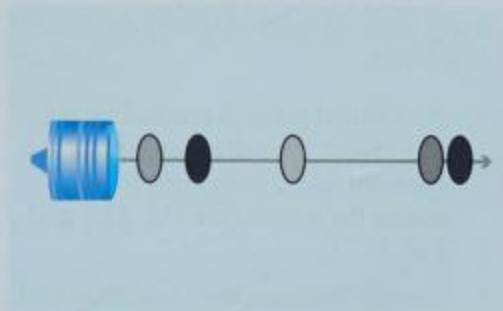


**Fig. 11.4** Diagram of a B-mode display. The horizontal, or x-axis, represents reflector depth. The amplitude of the reflection is represented by the brightness of the dot and is sent into the z-axis of an oscilloscope.



**Fig. 11.5** Actual B-scan or static image. This image is created with B-mode principles by directing sound beams into the patient and creating dots on the display. The brightness of each dot is related to the strength of the returning reflection.

### 3. M-mode—Motion

M-mode appears as a group of horizontal wavy lines. M-mode displays are created as follows:

- As a sound pulse is emitted by the transducer, the reflections move at a constant speed from right to left across the screen (see Fig. 11.6 and Fig. 11.7).
- Various squiggly lines that represent the changing depth of the reflecting surfaces are produced on the screen.

A line that moves up and down on the display indicates that a reflector is moving closer to or farther away from the transducer; hence, the name **motion mode**. A straight horizontal line indicates a stationary reflector.

- The **x-axis** (horizontal) of an M-mode display represents **time**.
- The **y-axis** (vertical) axis represents reflector **depth**, which is derived from the time-of-flight information of the sound pulse.

Since M-mode ultrasound information arises from a single penetration into the body, the “sampling rate” of M-mode is very high and is equal to the pulse repetition frequency of the system.

M-mode has been used primarily to assess the motion of cardiac walls and structures; its use is declining.

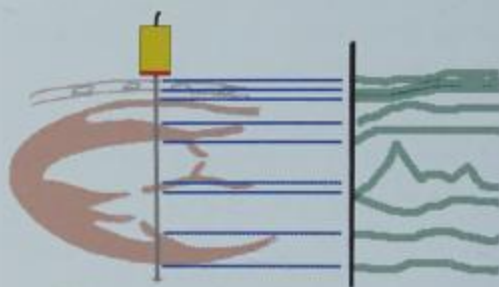


Fig. 11.6 Diagram of an M-mode display.

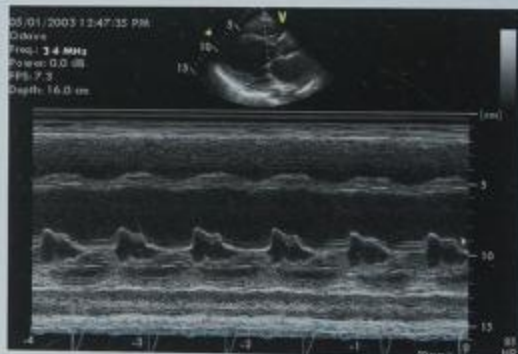


Fig. 11.7 Actual M-mode illustrating the changing position of moving cardiac structures in time. The horizontal, or x-axis, represents time. The vertical, or y-axis, represents reflector depth.

**Note:** Of the 3 modes discussed, M-mode is the only one that provides information about a reflector's changing location with respect to time.

Table 11.1 Display Mode Axes

| Mode   | X-axis | Y-axis    | Z-axis    |
|--------|--------|-----------|-----------|
| A-mode | depth  | amplitude | none      |
| B-mode | depth  | none      | amplitude |
| M-mode | time   | depth     | none      |

| Questions                                                                                                   | Answers                                          |
|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------|
| 1. What is the only display mode that provides information regarding reflector motion with respect to time? | 1. M-mode.                                       |
| 2. With A-mode, what is displayed on the x-axis?                                                            | 2. Depth of the reflector.                       |
| 3. With M-mode, what is displayed on the y-axis?                                                            | 3. Depth of the reflector.                       |
| 4. Which mode provides the foundation for real-time, gray scale anatomic imaging?                           | 4. B-mode, or brightness mode.                   |
| 5. With A-mode, what is displayed on the y-axis?                                                            | 5. Amplitude of the reflected signal.            |
| 6. In M-mode, what is displayed on the x-axis?                                                              | 6. Time.                                         |
| 7. With B-mode, which axis is related to the strength of the reflection?                                    | 7. The z-axis is related to reflection strength. |

## 2. Micro-Motion

The motion of a scatterer (e.g., a red blood cell) relative to the transducer is the sum of the motion of the transducer and the motion of the scatterer. This is the total motion of the scatterer relative to the transducer.

The motion of the transducer is the motion of the transducer relative to the patient. This is the motion of the transducer relative to the patient.

The motion of the scatterer is the motion of the scatterer relative to the transducer. This is the motion of the scatterer relative to the transducer.

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## Two-Dimensional Imaging

A-mode, one-dimensional B-mode, and M-mode techniques are used only in specific clinical settings. Today, clinicians acquire and interpret two-dimensional images that display slices of anatomy (see Fig. 12.1).

### *How does an ultrasound system create high quality, two-dimensional images?*

Two characteristics of sound make two-dimensional images challenging to make. First, sound travels in a straight line. Second, sound beams must be narrow to optimize lateral resolution. The use of multiple pulses to create a two-dimensional image overcomes both of these difficulties.

A modern ultrasound system sends a narrow sound pulse into the body, receives reflections, processes, and stores the data. The system automatically directs a second sound beam into the body at a slightly different direction than the first. The data are processed.

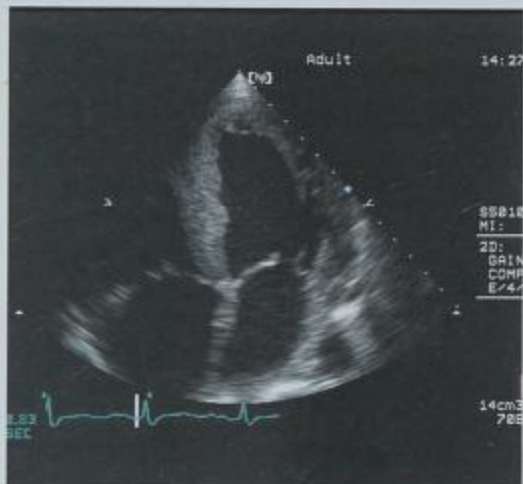


**Fig. 12.1** Two-dimensional ultrasound image of cardiac anatomy.

Then, the system automatically directs a third pulse into the body at another slightly different direction. This process is repeated numerous times, creating a two-dimensional image (see Fig. 12.2).

Sonographers are often unaware of this repetitive process because it is so rapid. Creating a 10-centimeter deep image with 90 individual ultrasound pulses takes slightly more than 1/100th of a second!

The mathematical details of image formation are not important. For now, simply appreciate that the creation of a two-dimensional image from multiple sound pulses penetrating the body is accomplished quickly.

The remainder of this chapter describes the different types of two-dimensional ultrasound transducers. Specific attention will be paid to five characteristics of each transducer style:

- shape and number of active elements in the transducer
- automatic redirection of the sound beams to create an image
- focusing of each sound beam
- shape of the two-dimensional image
- consequences of a damaged or nonfunctional active element in the probe



**Fig. 12.2** Creation of a two-dimensional image from multiple ultrasound pulses.

## Mechanical Transducer

The mechanical transducer contains a **single, circular, disc-shaped active element** that is physically moved. This movement creates a scan plane.

### Crystals: Number and Shape

Mechanical transducers can have only **one active element**. The element's shape resembles a coin.

### Image Shape

The image created by a mechanical transducer is **fan or sector-shaped**, similar to the sweeping of a wiper blade across a car's windshield. The pulses radiate out from the PZT crystal like the spokes of a bicycle wheel as it rotates around a single point (see Fig. 12.3).

With **greater depth, gaps of ever increasing size** exist between the scan lines.

### Beam Steering

The two-dimensional image is built up by rotating the crystal with a motor. Sound beams are emitted as the crystal moves. Hence, the scan plane is created through **mechanical steering**.

### Beam Focusing

Mechanical transducers have a **fixed focal depth**. This is called **conventional, mechanical, or fixed focusing**. Two methods of fixed focusing are:

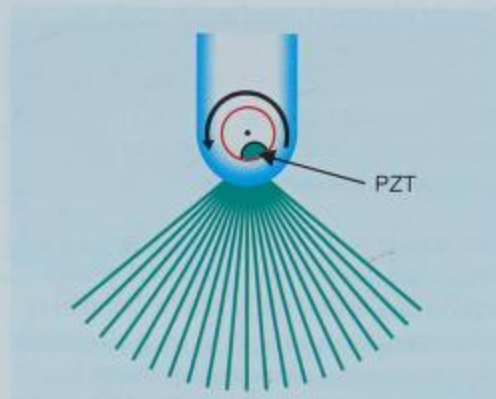


**Fig. 12.3** With a mechanical transducer, the PZT crystal is **physically moved** to create the image.

- **internal focusing** with the use of a curved active element, or
- **external focusing** with the use of an acoustic lens (see page 155).

Focusing occurs in both the horizontal and vertical planes because of the **hour-glass shape** of the sound beam.

### Damaged PZT Crystal

Mechanical transducers have only a single crystal; therefore, **the entire image is lost** when the crystal malfunctions.

**Hint:** Whenever the crystal in any single crystal transducer breaks, the entire image is lost.



## Transducer Arrays

Single element transducers, such as mechanical probes, are technically simple, and have been replaced by more sophisticated designs. Generally, modern transducers, called **arrays**, contain **multiple active elements**.

An array comprises a single slab of PZT cut into a collection of separate pieces called **elements**. Each active element is connected by a wire to its own electronic circuitry in the ultrasound system. Each element is acoustically isolated from its neighboring crystals. A **channel** is the combination of the active element, wire, and system electronics.

Since each element has its own electrical connection, the system can excite a single or multiple elements in various ways during transmission. During reception, each individual crystal produces a small electronic signal that returns to the system's receiver.

Three types of array transducers are listed in Table 12.1.

Table 12.1 Types of Array Transducers

| Type    | Arrangement                                                                                                               |
|---------|---------------------------------------------------------------------------------------------------------------------------|
| Linear  | Active elements are arranged in a straight line.                                                                          |
| Annular | Elements are arranged as circular rings with a common center.                                                             |
| Convex  | Active elements are arranged in a bowed or arched line. The transducer may also be called a curved, or curvilinear array. |



## Linear Phased Arrays

The linear phased array transducer is rather compact. The footprint, or the face of the transducer that comes into contact with skin, is a **small square** about 1 centimeter on each side (see Fig. 12.4). The linear phased array **has no moving parts**. The beam is **steered and focused** using an **electrical technique called phasing**.



Fig. 12.4 Linear phased array transducer.

### Crystals: Number and Shape

Although the footprint of a phased array probe is small, as many as **100 to 300 elements are arranged along the face of the probe**. Placed compactly **side by side**, each element is **rectangular and narrow**. The width of each element is  $\frac{1}{4}$  to  $\frac{1}{2}$  of the sound's wavelength (see Fig. 12.5).



Fig. 12.5 Elements of a linear phased array transducer are rectangular.

### Image Shape

The image created by a phased array transducer is **fan or sector-shaped**, similar to that produced by the mechanical transducer (see Fig. 12.6).

### Beam Steering

The two-dimensional image is built up with an **electronic steering process** called **phasing**. The sound beams are **electronically transmitted in different directions without the use of moving parts**. The pulses are directed in a pattern similar to that of the sweeping of a windshield wiper or the spokes of a bicycle wheel.

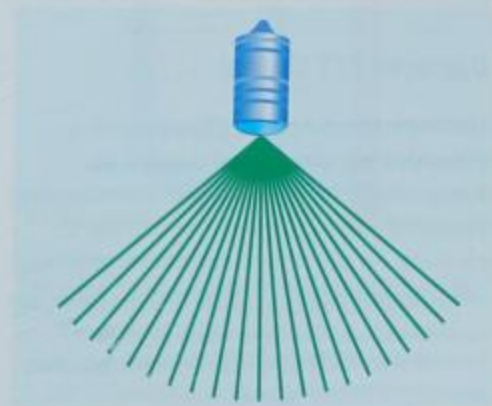


Fig. 12.6 With a phased array transducer, the sound beam is steered electronically without the use of moving parts.

## Beam Focusing

With linear phased array transducers, sound beams are **focused electronically**. Unlike mechanical transducers, which have a single fixed focus, the phased array system has controls that allow the sonographer to modify the depth and amount of focusing of the sound beam.

The obvious advantage of phased array systems is the availability of electronically controlled, adjustable focusing. This allows the sonographer to appropriately match the beam's characteristics to the clinical requirements.

Whether the region of clinical interest is superficial or deep, the sonographer can adjust the focal depth accordingly. In fact, **modern phased array systems can transmit multiple beams down the same scan line, each with a different focal depth, thus providing multi-focusing capability.**

**Note:** Phased array *always* means "adjustable" or "multi-focus."

## Damaged PZT Crystal

Damage to one of the elements of a **phased array transducer results in inconsistent or erratic beam steering and focusing.** The effect of the damaged element on the image **cannot be precisely determined because each sound pulse is created by a complex interaction of sound wavelets emitted by many active elements in the probe.**

## More About Linear Phased Array Transducers

*How many elements in a phased array probe are used to create a single sound pulse?*

All the active elements in a linear phased array probe are fired to create each sound pulse. For example, if a phased array transducer has 128 elements, all the elements are excited by electrical signals from each channel, and 128 small sound wavelets are created.

These wavelets interfere constructively and destructively creating a single sound pulse with particular characteristics. The overall pattern of the electrical signals from the ultrasound system determines the sound beam's direction and focus.

*In a phased array system, how does the pattern of electrical spikes from the ultrasound system steer the sound beam in different directions?*

Fig. 12.7 displays the interior of a linear phased array transducer. The green rectangles represent the PZT crystals. The red dots represent the electrical spikes created by the transmit channels in the ultrasound system. The spikes travel down the wires and excite the active elements at the end of the wires. The electrical signals are lined up and will arrive at each of their respective active elements at exactly the same time. Each active element creates a small sound wavelet. The wavelets interfere, forming a single sound beam.

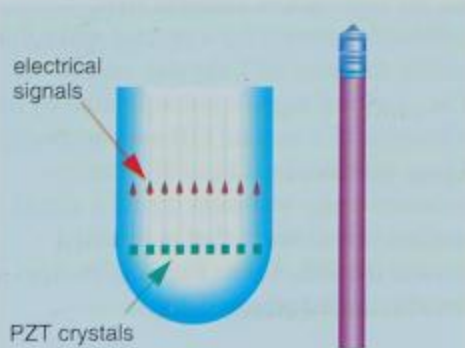


**Fig. 12.7** Each active element creates a small sound wavelet. The wavelets interfere and form a single sound beam. The electrical signals will arrive at each of their respective active elements at exactly the same time. This specific electrical pattern creates a sound beam that is directed straight down.



## Beam Steering—Linear Phased Arrays

*How can we determine the direction that the sound beam will transmit?*

The beam direction for a particular electrical pattern is determined with a two-step approach (see Fig. 12.8).

1. Draw a line (orange, solid line) that connects the electrical spikes.
2. Draw another line (orange, dashed line) extending out of the transducer that is perpendicular to the solid line.

The direction of the dashed line from step 2 indicates **sound beam steering**.

A different electrical spike pattern created by the ultrasound system appears in Fig. 12.9. This pattern of phasing starts with an electrical spike that excites the far right active element first, followed instantly by a second spike that strikes the next PZT crystal, and so on. The electrical signals are separated by ten billionths of a second (10 nanoseconds). These infinitesimal time differences between many wavelets create a single unified sound beam that is directed toward the left. These time differences are also called **phase delays**.

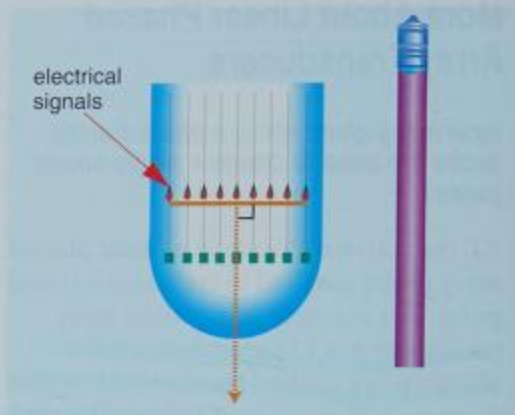


**Fig. 12.8** The slope of the electrical spike line determines the direction that the sound beam is steered.

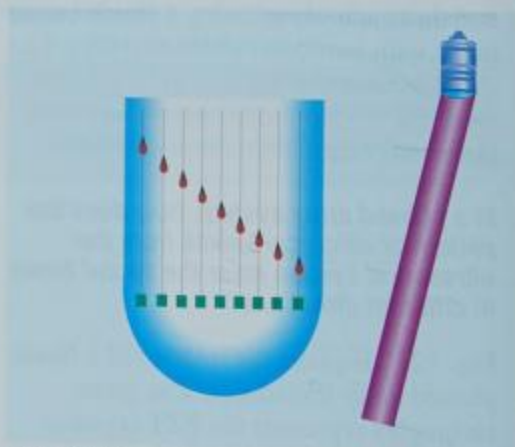


**Fig. 12.9** Beam steering to the left is achieved with this electrical pattern in a phased array transducer.

**Note:** The steering characteristics of a particular electrical pattern are identified by drawing a line that connects the electrical spikes. The sound beam is directed downward when the spike line is horizontal. **The sound beam is steered if the spike line has a slope.**



A different electrical pattern is illustrated in Fig. 12.10. In this example, a sloped pattern excites the far left active element first. The successive electrical spikes arrive nearly instantaneously from left to right. Again, the phase delays between electrical spikes is about 10 nanoseconds. This phasing pattern creates a single sound beam that is directed toward the right.

Phased array ultrasound systems are very sophisticated. Each electrical pattern is slightly different than the pattern before it. If the identical pattern was used, the ultrasound system would repeatedly transmit each sound pulse down the same line. However, these slight variations in the slope of the electrical pattern steer or sweep the sound beam in slightly different directions, creating a sector-shaped image. Beam steering is achieved electronically without any moving parts in the transducer.

The electronics within the ultrasound system that create these patterns is called the **beam former**.

In the previous three examples (Fig. 12.8 through Fig. 12.10), the electrical spikes could be connected by a straight line. When a **spike pattern is a straight line**, an unfocused sound beam is created.

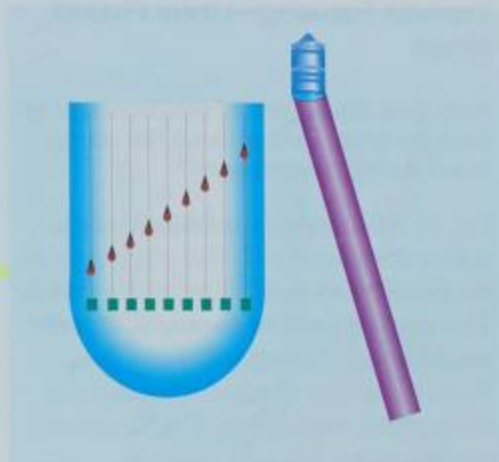


**Fig. 12.10** Beam steering to the right is achieved with this electrical pattern in a phased array transducer.

## Transmit Focusing—Linear Phased Arrays

*How does the pattern of electrical spikes from the beam former focus the sound beam during transmission?*

Fig. 12.11 illustrates electrical spikes with a curved pattern. The outer crystals are excited earlier than the inner crystals. This curved pattern creates a focused sound beam during transmission. Since there is no predominant slope to this pattern, the beam will be directed straight down; see orange lines.

**Note:** The focusing characteristics of a particular electrical pattern are identified by drawing a line that connects the electrical spikes. The sound beam is unfocused if the spike pattern is straight. The sound beam is focused if the spike pattern is curved.

Another example of electronic focusing is shown in Fig. 12.12. The curvature is more severe in this pattern than in Fig. 12.11. The sound beam created by this more curved electrical pattern will have a shallower focus. However, the sound beam will still be directed straight down.

**Hint:** To determine beam steering, draw a line from the far left to the far right spike. The direction of steering is perpendicular to this line.

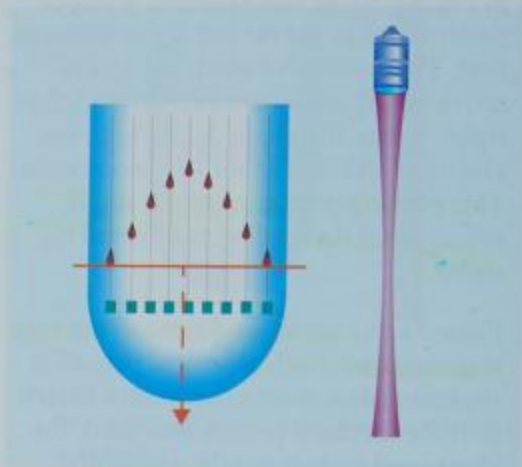


**Fig. 12.11** A focused, unsteered sound beam is created by this electrical pattern from the beam former of a phased array system.

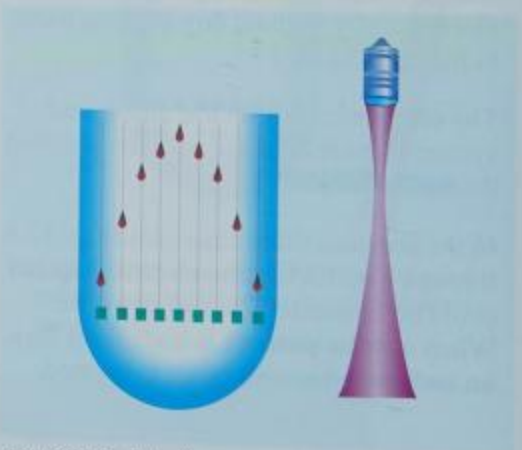


**Fig. 12.12** A shallower focused, unsteered sound beam is created by this electrical pattern from the beam former of a phased array system.

Fig. 12.13 shows a different phasing pattern that steers the beam to the left and focuses it during transmission. The electrical spike pattern is curved, creating a focused sound beam. In addition, this pattern of phasing has an overall slope that steers the beam to the left.

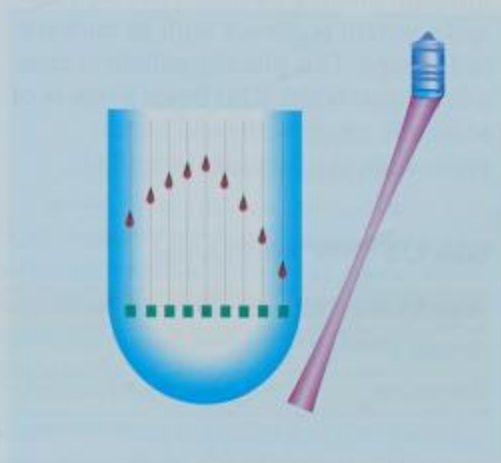


**Fig. 12.13** A focused beam steered to the left is created by this electrical pattern from the beam former of a phased array system.

Fig. 12.14 shows a different phasing pattern that steers the beam to the right and focuses it during transmission. The electrical spike pattern is curved, creating a focused sound beam. In addition, this pattern of phasing has an overall slope that steers the beam to the right.

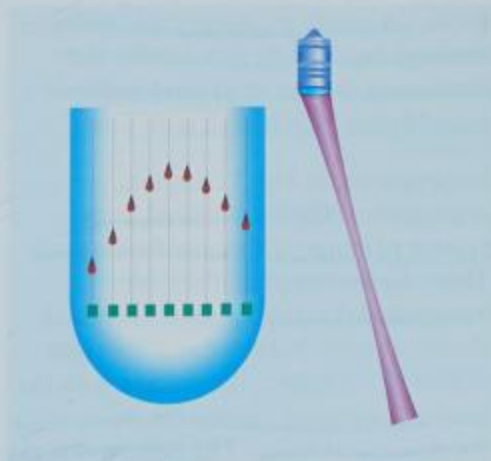


**Fig. 12.14** A focused beam steered to the right is created by this electrical pattern from the beam former of a phased array system.



Finally, Fig. 12.15 shows a completely different phasing pattern. The electrical spike pattern is convex with an outward or D-shape. This phasing pattern creates a defocused beam. This beam shape is of academic interest only and has no application in diagnostic imaging.

Table 12.2 Linear Phased Arrays

| Electronic Pattern | Sound Beam        |
|--------------------|-------------------|
| Slope              | Steering          |
| Curvature          | Transmit Focusing |

**How does a phased array system create images with multiple transmit foci?**

A focus can be considered the “waist” of a sound beam. Just as a person has a single waist, a sound beam has only one focus. To create an image with multiple transmit foci at different depths, the ultrasound system must send multiple sound beams down each scan line.

For example, in Fig. 12.16, the sonographer adjusts a phased array system to image with three focal points. Three distinct sound pulses are transmitted down each scan line. Each electrical spike pattern has a different degree of curvature; the pattern with the greatest curvature creates the beam with the shallowest focus. The pattern that is least curved produces the beam with the deepest focus. Each line in the image is created by the focal zones of the pulses.

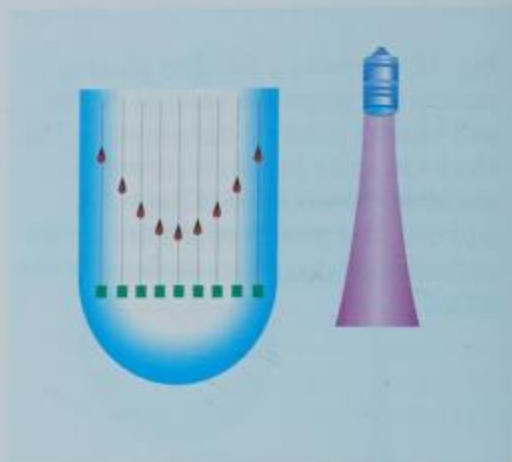


Fig. 12.15 A defocused sound beam is created by this D-shaped electrical pattern. This is not the overall image shape, but rather the profile of a single sound beam.

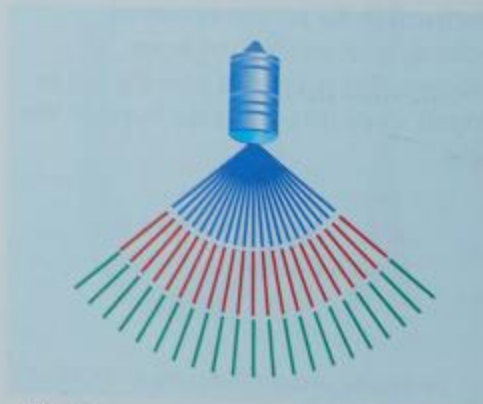


Fig. 12.16 Multi-focusing—three sound beams are transmitted down each scan line.



## Dynamic Receive Focusing

Focusing during transmission is illustrated in Fig. 12.11 through Fig. 12.14.

### *Can phase delays be used to focus a sound beam during reception?*

This question introduces the concept of dynamic receive focus. We have already learned how the curvature of the electrical pattern in a phased array transducer focuses a sound beam at a single depth **during transmission**. However, that is only part of the story regarding focusing. **Focusing may also occur during reception.**

During reception, when reflected sound arrives at the transducer, multiple neighboring elements in the probe are excited. These elements create electrical signals that return to the system's receiver via multiple channels.

A more accurate image can be created when the ultrasound receiver introduces **variable time delays** to some of these electrical signals **during reception**. The optimal time delays used during receive focusing depend upon the depth at which the reflection was created. Therefore, **the delay patterns during receive-focusing change continuously** as the transducer listens for reflections.

With dynamic receive focusing, the reflected sound is focused at many depths. This differs from transmit focusing, which is limited to a single focal point.

Dynamic receive focusing is performed automatically by the ultrasound system and is not controlled by the sonographer.

## Annular Phased Arrays

### Crystals: Number and Shape

The active elements of annular array transducers appear **disc-like**. Rather than a single element, **the disc actually comprises multiple ring-shaped elements with a common center**. Their appearance is similar to the rings that appear on a **bull's-eye target** (see Fig. 12.17).

### Beam Steering

With annular phased array transducers, **mechanical steering** creates the **two-dimensional image**. A motor physically moves the ringed-element array so that **the sound beams are transmitted in different directions**. Electronic steering is not possible with annular arrays.

### Beam Focusing

The primary advantage of annular phased arrays is that **multiple transmit focal zones** create each scan line of the image. Remember, the term phased array means either **adjustable** or **multi-focus**, and in the case of annular phased arrays, the term means **multi-focus** (see Fig. 12.18).

Recall from page 135 that **smaller diameter PZT crystals create shallow focus beams**, whereas **larger diameter crystals create deeper focus beams**.

The **inner crystal of an annular phased array transducer creates a shallow focus beam** and information only from the **shallowest depths** is collected; all

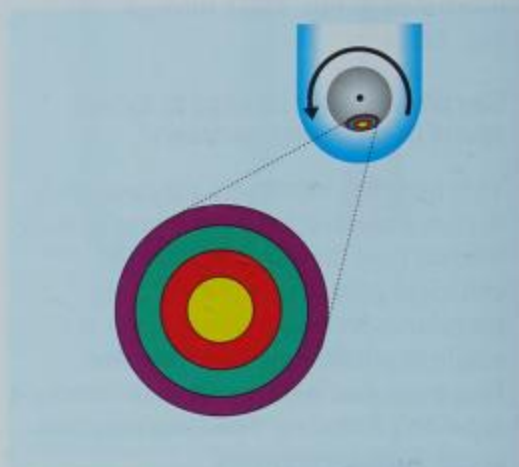


**Fig. 12.17** Annular phased array transducer. Inner rings of the array acquire data from shallow depths. Outer rings acquire data from deeper regions.

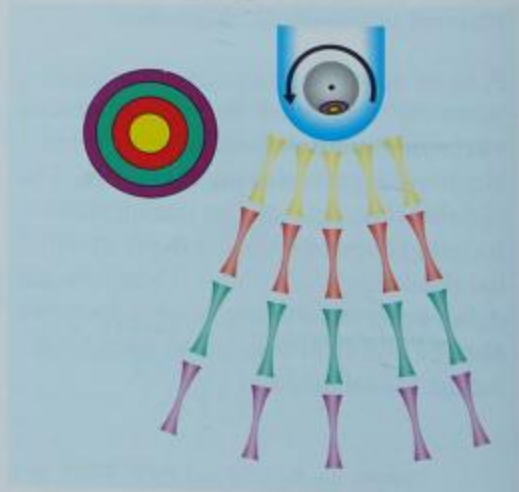


**Fig. 12.18** Multi-focusing capability of an annular array transducer.

remaining information from the inner crystal's reflected sound pulse is ignored. Then the next larger crystal is fired down the same scan line, and only information from its focal zone is processed. This is repeated for each of the rings.

Information is stored only from the respective focal zone, which gets progressively deeper with every ring.

Therefore, an annular array comprising 4 ringed elements transmits 4 pulses down each scan line, each with a different focal depth. The final image is a composite of information from only the focal zone of each crystal.

### Image Shape

Since the beam steering of an annular array transducer is mechanical, the image is **fan or sector shaped**. The sound beams are emitted from the transducer like the spokes of a bicycle wheel.

### Damaged PZT Crystal

When one ring of an annular array transducer malfunctions, **only a portion of the image is lost**. This will appear as a horizontal or side-to-side band of dropout at a particular depth (see Fig. 12.19).

Recall that each ring of an annular array is responsible for collecting image data from its focal zone. If the innermost ring malfunctions, the most superficial region of the image is lost. If an outer ring malfunctions, a deeper horizontal band of the image is lost.

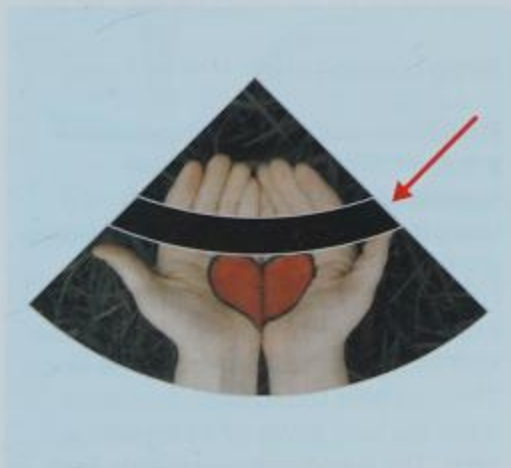


**Fig. 12.19** Malfunction of an element within an annular phased array transducer results in a horizontal band of dropout (red arrow).



## Linear Sequential Arrays

So far, we have discussed transducers that create sector-shaped images. These transducers have small acoustic footprints (area of the transducer that comes in contact with the skin).

The linear sequential array, or linear switched array (see Fig. 12.20) has a large acoustic footprint and creates rectangular images.

### Crystals: Number and Shape

A linear sequential array has 120 to 250 rectangular-shaped strips of piezoelectric material arranged side by side in a line. The active elements in linear sequential arrays are much larger than those found in linear phased arrays. Each crystal is about 1 wavelength in width. The array is large, up to 10 cm long (see Fig. 12.21).

### Beam Steering

With linear sequential arrays, a small group of the crystals are fired simultaneously to create each sound beam (see Fig. 12.22). The sound beams are parallel to each other and are typically directed straight ahead. For example, the simultaneous firing of the first 10 crystals creates one sound beam. Then, another sound beam is created when the next group of 10 crystals is fired. The sound pulses originate from different locations along the face of the probe when different sets of crystals are excited.



Fig. 12.20 Linear sequential, or linear switched, array transducer.



Fig. 12.21 Individual elements of a linear sequential array transducer are rectangular. Unlike this schematic, there are actually 120 to 250 elements arranged side by side.

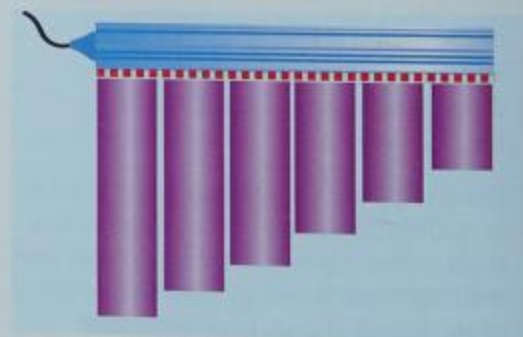


Fig. 12.22 Individual sound beams from a linear sequential array are created by firing a small group of elements in the array.



## Beam Focusing

In earlier models of linear sequential arrays, beams were focused conventionally with curved active elements (internal focus) or by placing a lens in front of the active elements (external focus). In this setting, focusing characteristics were fixed and the sonographer could not alter them (see Fig. 12.23).

In modern linear sequential arrays, focusing is achieved electronically. Modern linear sequential arrays perform both transmit and receive focusing using electronic phase delays.

Just like linear phased arrays, **electronic transmit focusing** is achieved with a curved excitation pattern of the active elements (see Fig. 12.24). The outer elements in the group of PZT crystals are fired earlier than the inner elements.

**Receive focusing** is achieved dynamically by introducing electrical delays in the signals returning from the transducer. The phase delays change continuously during reception, thereby focusing the beam at many depths.

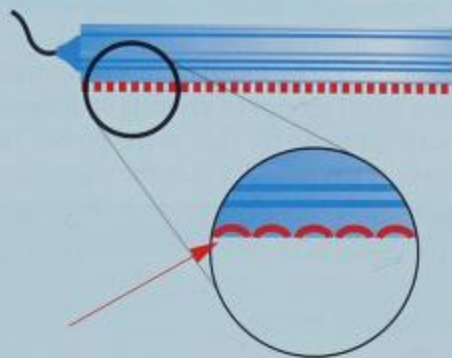


**Fig. 12.23** Fixed focusing techniques, such as curved active elements (arrow), were used in basic linear sequential array transducers.

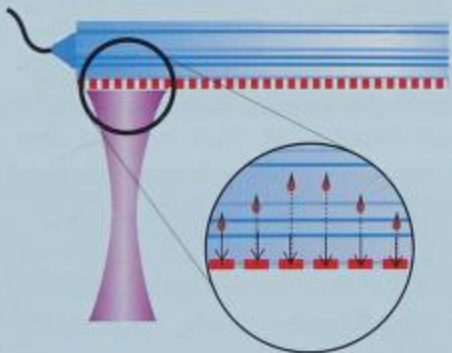


**Fig. 12.24** Electronic focusing is commonly used with linear sequential arrays.

## Image Shape

A **rectangular image** is created with a **linear sequential array transducer** (see Fig. 12.25). The sound beams are emitted from small groups of crystals at different locations along the face of the probe. The image is never wider than the transducer. Although a transducer with a 10 cm footprint may produce an 8 cm wide image, it cannot create an image wider than 10 cm.

## Damaged PZT

When one element in a linear sequential array is damaged, only the portion of the **image** extending directly below the **damaged element** is affected (see Fig. 12.26).

Recall that only a small subset of the transducer's active elements is fired for each sound pulse. Thus, only the scan lines that would have been created by the defective crystal are affected.

## More About Linear Sequential Array Transducers

*While using linear array transducers, why is it necessary to fire a group of crystals to produce a sound beam? Why can't a single crystal be used instead?*

Recall that **sound waves** produced by a **small active element** diverge in a **spherical shape** or a **Huygens' wavelet** (see page 142). A sound wave fired from a single element of a linear sequential



Fig. 12.25 A rectangular image is created by a linear sequential array transducer.



Fig. 12.26 Malfunction of an element (yellow) within a linear sequential array transducer results in a band of dropout extending from the top to the bottom of the image.

array would have such a shape. The beam would quickly diverge and result in poor lateral resolution. In contrast, a sound beam created by the combination of wavelets from a small group of active elements is directional and well defined.

***Can linear sequential array transducers steer sound beams electronically?***

Yes, linear arrays can steer sound beams electronically. This form of beam steering creates **parallelogram-shaped images** rather than rectangular images (see Fig. 12.27). As previously described, beam formers of phased array systems steer sound beams electronically. **Sloped-patterned phase delays** in the electrical excitation spikes of the elements steer the beam (see page 172).

In Fig. 12.28, a rectangular, gray scale anatomic image is created during color Doppler exams with a linear array. The electrical patterns creating sound beams for the gray scale image have no slope, and the sound beams are directed straight down. However, the **color Doppler portion of the image is parallelogram shaped** because the electrical spike patterns creating the Doppler sound beams are sloped.



**Fig. 12.27** Image created by a modern linear sequential array transducer. Note that the beams can be electronically steered to form a gray scale image in the shape of a parallelogram rather than a rectangle.

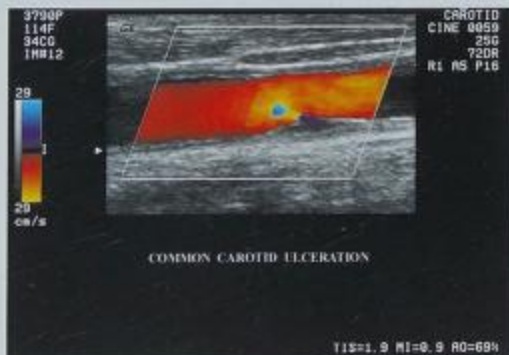


**Fig. 12.28** Color Doppler image created by a modern linear sequential array transducer. The beams used for color Doppler are electronically steered at an angle to form a parallelogram shape.



## Convex, Curved, or Curvilinear Array Transducers

To increase the clinical utility of linear array probes, manufacturers have designed arrays with a bowed, or curved shape. These transducers are called **convex, curved, or curvilinear** (see Fig. 12.29). The operational characteristics of convex arrays are similar to those of linear arrays.

### Crystals: Number and Shape

A convex array has 120 to 250 rectangular shaped strips of piezoelectric material arranged side by side in a bowed line. The array is large. The acoustic footprint may be as long as 10 cm. Note that the active elements in a convex sequential array are similar in size to a linear array, and much larger than those found in a phased array. Each crystal is about 1 wavelength in width.

### Beam Steering

In convex sequential arrays, **some, but not all, of the crystals are fired simultaneously to create each sound beam**. The beam is directed straight out of the crystals, but since the crystals are arranged in an arc, the pulses travel in different directions as they radiate out from the transducer (see Fig. 12.30). The sound beams transmitted from a convex array, unlike linear sequential arrays, are not parallel to each other.



Fig. 12.29 Convex sequential array transducer.



Fig. 12.30 Image creation with a convex sequential array is achieved by firing a small group of elements in the array.



## Beam Focusing

**Focusing** in modern convex arrays is achieved **electronically**. Just like linear array probes, transmit focusing in convex arrays is achieved by exciting the active elements in the fired group with a **curved spike line pattern**.

**Dynamic receive focusing** is achieved by introducing varying phase delays in the signals returning from the transducer to the ultrasound system during echo reception.

## Image Shape

**Blunted sector-shaped** images are created by a convex array (see Fig. 12.31). At intermediate depths, these images have a traditional sector shape; however, rather than coming to a point in the near field, the image appears to have a “bite” taken out of it. The curvature at the top of the image corresponds directly to the arc of the convex array transducer. Convex array transducers create images with a shape of a natural sector.

## Damaged PZT Crystal

When one active element in a convex array is damaged, only the portion of the image directly below the damaged element is affected (see Fig. 12.32). Recall that only a small subset of the transducer’s active elements is fired for each scan line. Thus, only the scan lines from the defective crystal are affected by its malfunction.



**Fig. 12.31** Images in the shape of a blunted sector are created by a sequential array transducer.



**Fig. 12.32** Malfunction of an element within a convex sequential array transducer results in a band of dropout extending from the top to the bottom of the image (red arrow).

## Vector Arrays

A vector array is a combination of linear sequential and linear phased array technologies. Sloped phase delay patterns can electronically steer the sound beams in different directions. This technology is called **vector** or **virtual sector**.

### Crystals: Number and Shape

A vector array is designed with 120 to 250 rectangular-shaped strips of piezoelectric material arranged side by side in a line. The footprint of the vector array may be small, often only a few centimeters (see Fig. 12.33).

### Beam Steering

Beam steering in vector arrays combines linear and phased array technologies. Some, but not all, of the crystals are fired simultaneously to create a single sound beam in vector arrays. This is similar to a linear sequential array transducer.

The electrical signals from the beam former are delayed in a sloped spike-line pattern as they excite a group of elements in a vector array. As a result, the beams radiate out in different directions from the face of the transducer. This is similar to a phased array transducer.



Fig. 12.33 Vector array transducer.

## Beam Focusing

**Electronic focusing** is used with vector arrays. Similar to the phased array probes, both transmit focusing and dynamic receive focusing improve lateral resolution over a great range of depths.

## Image Shape

**Trapezoidal images** are created by vector array transducers. At intermediate and deep depths, the image appears as a sector. However, unlike phased or convex array images, the top of the vector array's image is flat (see Fig. 12.34).



**Fig. 12.34** Vector array transducers create trapezoidal shaped images. Note the image has a flat top with a sector-like shape.

**Table 12.3** Active Element Malfunction

| Transducer Type          | Effect on image                                                                                                                   |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Mechanical               | Loss of entire image.                                                                                                             |
| Linear and Convex Arrays | Dropout of image information from the top to the bottom of the image. The location of the line corresponds to the broken crystal. |
| Phased Arrays            | Erratic steering and focusing. The extent to which the image is affected is variable.                                             |
| Annular Phased Arrays    | A horizontal or side-to-side band of dropout at a particular depth.                                                               |

**Table 12.4** Summary of Transducers

| Transducer        | Image Shape    | Steering Technique | Focusing Technique |
|-------------------|----------------|--------------------|--------------------|
| mechanical        | sector         | mechanical         | fixed              |
| linear sequential | rectangular    | electronic         | electronic         |
| phased array      | sector         | electronic         | electronic         |
| annular phased    | sector         | mechanical         | electronic         |
| convex            | blunted sector | electronic         | electronic         |
| vector            | trapezoidal    | electronic         | electronic         |



## Slice Thickness or Elevational Resolution

**Resolution** is accuracy in imaging. In addition to axial and lateral resolution, **slice thickness or elevational resolution** contributes to image quality.

Image resolution actually deals with three-dimensional space:

- shallow-to-deep
- side-to-side, and
- above-to-below the imaging plane.

Slice thickness is **measured in a direction perpendicular to the imaging plane or above-to-below the imaging plane.**

We assume that the plane of our ultrasound image is razor thin; however, this assumption is not always correct. The beam has a measurable thickness that can vary with depth.

When the slice is thick, structures above and beneath the “assumed razor-thin plane” create reflections that appear in the image.

### Slice Thickness Resolution

Slice thickness resolution answers the following question: *are the reflections on the image created from structures directly in the imaging plane or from structures that lie above or beneath the imaging plane?*

#### Synonym

Slice thickness resolution is also called **elevational resolution**.



## More About Elevational Resolution

*What shape of active element creates the best elevational resolution?*

*Which transducer types have the best elevational resolution?*

Active elements that are disc shaped provide the thinnest ultrasound slices and the best elevational resolution within the focal zone. Disc-shaped crystals are found in mechanical and annular phased array transducers.

With disc-shaped crystals, the cross section of a sound beam is a circle. The width of the circle in one direction indicates the beam diameter (determining lateral resolution), and the height of the circle indicates the beam thickness (determining elevational resolution). The elevational resolution is identical to the lateral resolution with disc-shaped active elements (see Fig. 12.35).

*What determines elevational resolution in phased array, linear array, and convex array transducers?*

These array probes have rectangular-shaped active elements placed side by side. With phasing, the beam is focused or narrowed only side to side in the imaging plane, but not above and below. This narrowing improves lateral resolution but does not affect slice thickness.

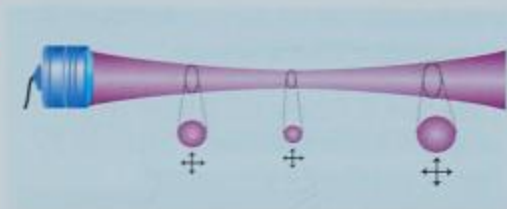


Fig. 12.35 Disc-shaped crystals produce beams with equal lateral and elevational resolution.

With these array probes, an acoustic lens is used to create a thinner slice. Recall that lenses have a fixed focal depth (see Fig. 12.36). At the transducer, the beam thickness is equal to the height of the active element. At the focal depth, the beam thins to its minimum value. At greater depths, the beam thickens substantially. At all depths, the beam is much thicker than it is wide.

Therefore, for these transducer styles, axial resolution is the best, followed by lateral, and finally, elevational.

***One limitation of linear arrays is the inability to dynamically create thin slices. What newer types of transducers have improved slice thickness resolution?***

Newer transducers, called one and one-half dimensional arrays, create thinner beams with improved slice thickness resolution over a greater range of depths. The face of the  $1\frac{1}{2}$ -D array transducer has numerous crystals arranged side by side. Unlike traditional linear, phased, and convex probes, which have a single crystal occupying each space, the  $1\frac{1}{2}$ -D array has multiple crystals in the up-and-down direction (see Fig. 12.37).

For example, the array might comprise 700 total elements, 100 wide by 7 high. Phasing, similar to that which improves lateral resolution, can be applied to the 7 vertical crystals, thereby thinning the slice and improving elevational resolution. Compare Fig. 12.36 and Fig. 12.37.

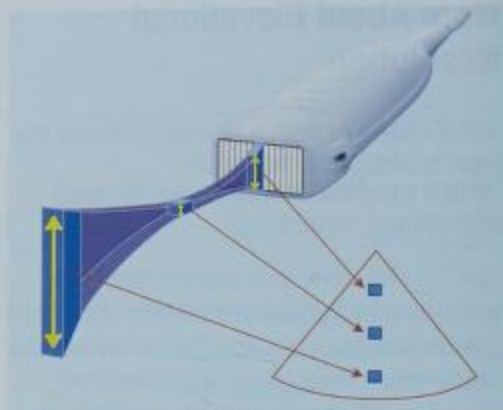


**Fig. 12.36** Elevational resolution (yellow arrows) with phased, linear, and convex array transducers. All three transducer arrays have rectangular active elements.

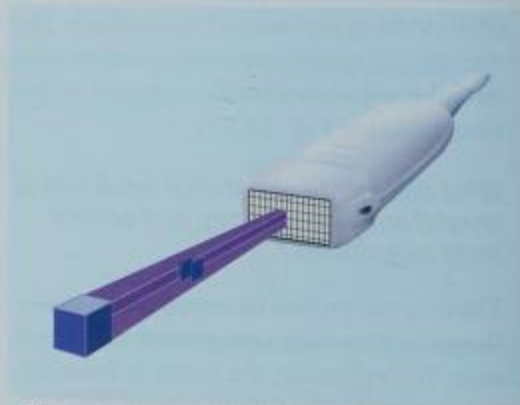


**Fig. 12.37** A  $1\frac{1}{2}$  dimensional array transducer has a few elements in the up-and-down direction to focus the beam in the thickness plane. This improves elevational resolution.

## Three-Dimensional Imaging

Three-dimensional (3-D), or volume imaging, is a recent innovation in ultrasound. A **2-D array** (see Fig. 12.38), with thousands of elements arranged in a checkerboard pattern, creates 3-D images (see Fig. 12.39).

With 2-D array transducers, the sound beams are electronically focused in both the lateral and thickness planes. The beams are electronically steered, creating entire scan planes that sweep through anatomic structures.

You may encounter the term **4-D imaging**. 4-D is simply a trendy way of describing **real-time 3-D imaging**. 4-D imaging also uses 2-D array probes.

**Rendering** creates an image from three-dimensional data acquired during the ultrasound exam. It provides an element of realism to the image (see Fig. 12.40).

Rendering constructs photo-like pictures with color, shadows, texture, and optical effects. Unlike regular photography, however, the images are computer generated. This provides creative control over what appears in the rendered image.

3-D rendering is often performed on an off-line, stand-alone computer system after the ultrasound data has been acquired and stored. Under these conditions, 3-D rendering is post-processing (see page 249). An example of this technique is its use in creating classic 3-D animated movies such as *Lion King* and *Toy Story*.



Fig. 12.38 Two-dimensional array transducer.



Fig. 12.39 3-D image of the heart, created with two-dimensional array transducers.



Fig. 12.40 A 3-D rendered image.



## Special Topics

### Side Lobes

Sound beams created by **single element transducers** are hourglass shaped. However, **additional areas of sound energy extend outside of the main beam in the far zone.** These off-axis sound beams are called **side lobes** (see Fig. 12.41).

Typically, the beam's **main axis is much stronger than the side lobes.** If however, the lobes are of sufficient intensity, **structures within them can generate reflections that create artifacts.** Reflections arising from within the side lobes **degrade lateral resolution.**



**Fig. 12.41** Side lobes, from mechanical scan heads, diminish image quality by degrading lateral resolution.

### Grating Lobes

Grating lobes are similar to side lobes; however, they are created by **array transducers.** Typically, the beam's **main axis is much stronger than the grating lobes.** These extra, off-axis sound beams are **undesirable because they degrade lateral resolution, reduce image quality, and create artifacts** (see Fig. 12.42).



**Fig. 12.42** Grating lobes from array transducers diminish image quality by degrading lateral resolution.

**Modern transducers are designed to reduce the strength of side and grating lobes. How is this accomplished?**

Since lobes can create artifacts, it is best to eliminate them. Reducing the strength of side and grating lobes can be achieved through a process called **apodization**.

Fig. 12.43 illustrates apodization. Imagine that 9 active elements of a linear array create a sound beam. When all 9 elements are excited by electrical spikes of similar voltage, grating lobes may be created. Grating lobes can be eliminated if the strength of the electrical spikes differs from element to element. In apodization, stronger electrical signals are used to excite the inner crystals, and progressively weaker electrical spikes excite the outer crystals. With apodization, lobes are diminished.

**Subdicing** of each element in a linear array transducer also reduces grating lobes. With subdicing, a crystal is divided into a group of smaller crystals called sub-elements. These sub-elements are electrically joined, and act as if they are a single crystal, which reduces grating lobes.



**Fig. 12.43** Apodization alters the electrical spike voltages and reduces lobe strength.

*Modern transducers are designed to keep the sound beam narrow over a substantial depth range. How is this accomplished?*

A technique called **dynamic aperture** can be used to make a sound beam narrow over a greater range of depths and thus optimize lateral resolution.

We have previously learned that **transducer diameter**, in part, determines **beam width**. The focus created by a **small-diameter active element** is shallow, whereas the focus from a **large-diameter active element** is deep.

When an array transducer is used, the ultrasound system may change the number of crystals along the face of the probe used to transmit pulses and receive reflections. This process is called changing the aperture, **variable aperture**, or **dynamic aperture**. An aperture is an opening or hole.

The aperture may be thought of as the “**transmit hole**” or the “**listening hole**”; that is, the number of elements used to **create sound beams** or to **receive reflected echoes**. Dynamic aperture improves lateral resolution at a wide range of depths.



## Review: Two-Dimensional Imaging

| Questions                                                                                                                                                                                                                       | Answers                                                                                                                                                                                 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. True or False. Mechanical scanning produces pictures that are similar in shape to linear phased array images.                                                                                                                | 1. True. Mechanical scanning and linear phased arrays create sector-shaped images.                                                                                                      |
| 2. True or False. Many active elements fire at almost the same time in a mechanical scanner.                                                                                                                                    | 2. False. There is only one active element in a mechanical scanner.                                                                                                                     |
| 3. True or False. Many active elements fire <b>at almost the same time</b> in a phased array scanner.                                                                                                                           | 3. True. Many active elements fire at almost the same time in a phased array scanner.                                                                                                   |
| 4. Which of the following transducers is best described as mechanically steered and fixed, single focused?<br>A. annular phased array<br>B. annular array<br>C. mechanical<br>D. linear phased                                  | 4. C. A mechanical transducer steers the sound beam mechanically. The sound beam has a single fixed focus.                                                                              |
| 5. Which of the following is best described as mechanically steered and multi-focus?<br>A. annular phased array transducer<br>B. annular sequential array transducer<br>C. mechanical transducer<br>D. linear phased transducer | 5. A. Annular phased array transducers steer the sound beams mechanically. They are multi-focused.<br><br>By the way, there is no such thing as an annular sequential array transducer. |
| 6. Which of the following transducers creates a rectangular shaped image?<br>A. annular phased array<br>B. linear sequential array<br>C. mechanical<br>D. linear phased                                                         | 6. B. A linear sequential array transducer is the only one of these choices that creates a rectangular shaped image.                                                                    |

| Questions                                                                                                                                                                               | Answers                                                                                                                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| 7. A linear phased array transducer has 128 crystals. How many of these crystals are fired to create a single sound beam?<br>A. 1<br>B. a small group<br>C. a large group<br>D. 128     | 7. D. With linear phased array transducers, all of the active elements are fired to create each sound pulse.           |
| 8. A linear sequential array transducer has 128 crystals. How many of these crystals are fired to create a single sound beam?<br>A. 1<br>B. a small group<br>C. a large group<br>D. 128 | 8. B. With linear sequential array transducers, a small group of active elements are fired to create each sound pulse. |
| 9. In a linear phased array, what is the firing pattern that steers a beam to the left or right?                                                                                        | 9. The firing pattern that steers a beam to the left or right is <b>electronic slope</b> .                             |
| 10. In linear phased arrays, what is the firing pattern that focuses a sound beam?                                                                                                      | 10. The firing pattern that focuses a sound beam is <b>electronic curvature</b> .                                      |
| 11. True or False. There are large time delays in the firing pattern of a linear phased array transducer.                                                                               | 11. False. There are tiny time delays in the firing pattern of a linear phased array transducer.                       |
| 12. True or False. A machine that displays A-mode and two-dimensional images is called a duplex scanner.                                                                                | 12. False. A machine that displays Doppler and two-dimensional images is called a duplex scanner.                      |
| 13. Which of the following improves elevational resolution?<br>A. matrix array<br>B. linear phased array<br>C. one and one-half dimensional array<br>D. two-dimensional array           | 13. C. A one and one-half dimensional array transducer creates a thin slice and improves elevational resolution.       |
| 14. True or False. Side lobes degrade axial resolution.                                                                                                                                 | 14. False.                                                                                                             |
| 15. True or False. Side lobes degrade lateral resolution.                                                                                                                               | 15. True.                                                                                                              |

## Real-Time Imaging

In the early days of diagnostic ultrasound, creating a single, two-dimensional image was time consuming. Images were displayed one frame at a time in a process called **static scanning**. It was impossible to image moving structures.

Today, however, all modern ultrasound instruments are capable of real-time imaging. Each frame is created and displayed very quickly, providing the impression of constant motion. Think of static scanning as an ultrasound “photograph” and real-time imaging as an ultrasound “movie.”



## Temporal Resolution

### Frame Rate

The most important operational parameter associated with an ultrasound “movie” is the system’s ability to create numerous frames each second. This parameter is called the **frame rate**.

#### Determined by

Frame rate is determined by two factors:

- sound’s speed in the **medium**
- the depth of imaging.

The speed of sound in soft tissue is considered to be constant at 1.54 km/s. In clinical ultrasound, the maximum imaging depth determines frame rate.

#### Units

Frame rate is measured in hertz (Hz), or “per second.” The units of frame rate are “images per second.”

### Temporal Resolution

Temporal resolution, which pertains to “accuracy in time,” describes the ability to precisely position moving structures from instant to instant.

Temporal resolution is excellent when a system produces many frames per second, and substandard when it produces few frames per second.

#### Determined by

Temporal resolution is determined by frame rate.

Displaying a high number of images per second (high frame rate) improves temporal resolution.

Temporal resolution is reduced when few images are displayed per second (low frame rate).

#### Units

Temporal resolution is related to frame rate, which also has units of hertz, or “per second.”

### Factors Affecting Frame Rate

- speed of sound in the medium
- imaging depth

**What is the relationship between frame rate and the time required to make a single image?**

Frame rate and time for one frame ( $T_{\text{frame}}$ ) are **inversely related**, and are **reciprocals**. When the frame rate is multiplied by  $T_{\text{frame}}$ , the result is 1:

$$T_{\text{frame}} \times \text{frame rate} = 1$$

For example:

- when an ultrasound system creates an image in 1/10 of a second, the frame rate is 10 frames/second or 10 Hz.
- when a system creates an image in 1/50 of a second, the frame rate is 50 frames/second or 50 Hz.

These mathematical examples illustrate that as the **time needed to make each image decreases**, the frame rate increases.

## System Settings That Determine Frame Rate

Two **sonographer-controlled** settings of an ultrasound system determine frame rate:

1. imaging depth
2. number of pulses in each picture

Frame rate affected by

- speed of sound in med
- imaging depth

Frame rate determined by

- imaging depth
- # of pulses/frame

### System Settings Affecting Frame Rate

- imaging depth
- number of pulses per frame

# 1. Imaging Depth

*How does imaging depth affect temporal resolution?*

Shallow imaging increases frame rate and improves temporal resolution. Deeper imaging decreases frame rate and degrades temporal resolution. Thus, **imaging depth and frame rate are inversely related** (see Fig. 13.1 and Fig. 13.2).

**Table 13.1 Imaging Depth and Temporal Resolution**

| Shallow Imaging                | Deep Imaging                   |
|--------------------------------|--------------------------------|
| • short go-return time         | • long go-return time          |
| • shorter $T_{\text{frame}}$   | • longer $T_{\text{frame}}$    |
| • higher frame rate            | • lower frame rate             |
| • superior temporal resolution | • inferior temporal resolution |

## Example

Assume that an ultrasound system creates each image with 100 distinct sound pulses. Furthermore, each pulse travels to a maximum depth that requires a round-trip time (also called the pulse repetition period, or PRP) of 1/1000 second. The time needed to make a single frame will be:

$$T_{\text{frame}} = \# \text{ pulses} \times \text{PRP}$$

$$= 100 \times 1/1000 \text{ second} = 1/10 \text{ second}$$

Therefore, the frame rate is 10 Hz.

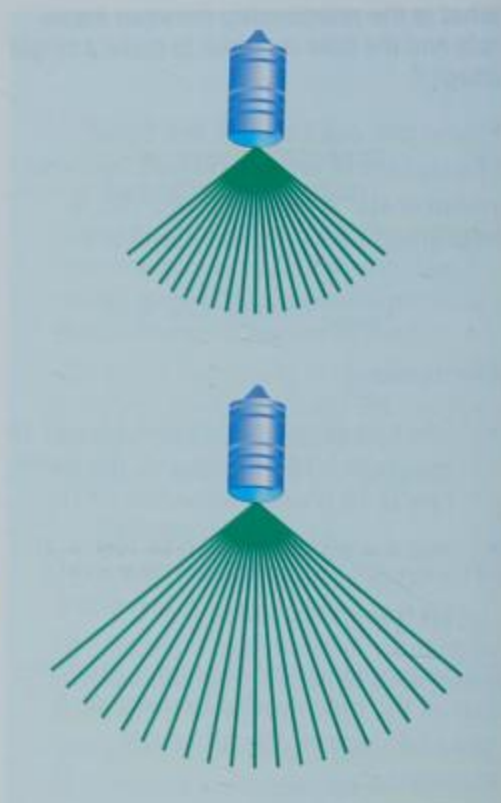


**Fig. 13.1** Imaging depth and  $T_{\text{frame}}$  are directly related. Shallower imaging results in less time needed to make each frame and a higher frame rate (upper). Deeper imaging results in a lower frame rate (lower).



Now, imagine that the sonographer adjusts the depth of view to half as deep. The pulse's time of flight will be  $0.5/1000$  sec. (If a pulse travels half as deep, the go-return time is half as long.) Since the image still requires 100 pulses, the time to make a frame is now:

$$= 100 \times 0.0005 \text{ second}$$

$$= 0.05 \text{ second or } 1/20 \text{ second}$$

The frame rate increases to 20 Hz and temporal resolution is improved.

## 2. Number of Pulses per Image

*How does the number of pulses in each image affect temporal resolution?*

Higher frame rates are possible when each individual image is made with fewer pulses. Lower frame rates occur when each image is made with more pulses. **Pulses per frame and frame rate are inversely related.**

*What factors affect the number of pulses needed to create an image?*

Three factors determine the number of pulses needed to create each image:

- number of pulses per scan line (multi-focus vs. single focus)
- sector size, and
- lines per angle of sector (line density).

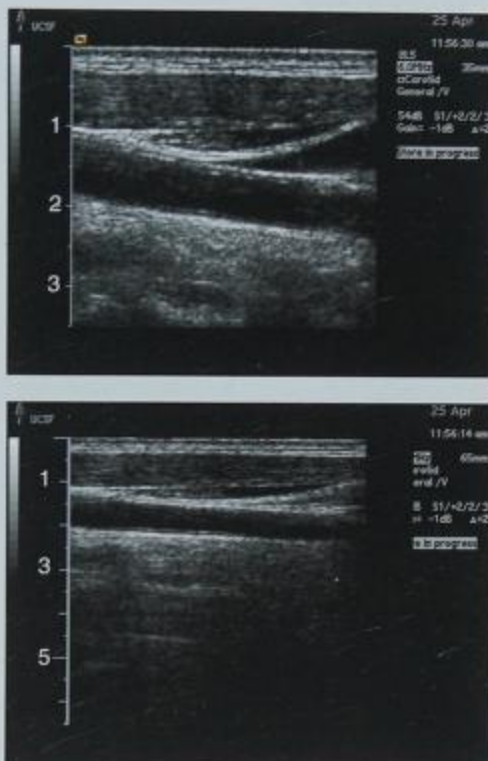


**Fig. 13.2** Imaging depth and  $T_{\text{frame}}$  are directly related. The upper, shallow image has a higher frame rate than the lower, deep image. The numbers indicating depth (cm) have been added for illustration purposes.

**Table 13.2** Factors that Affect the Number of Pulses

| Factors Determining Number of Pulses per Frame |
|------------------------------------------------|
| • number of focal points                       |
| • sector size                                  |
| • line density                                 |

## Multi-focus

Recall that an individual sound beam has only one focus. With single focus imaging, only one sound pulse is transmitted down each scan line.

When the sonographer activates multiple focal zones, more pulses are transmitted down each scan line, and the number of pulses required to create an image increases accordingly. As a result, multi-focusing decreases the frame rate, and diminishes temporal resolution (see Fig. 13.3 and Fig. 13.4).

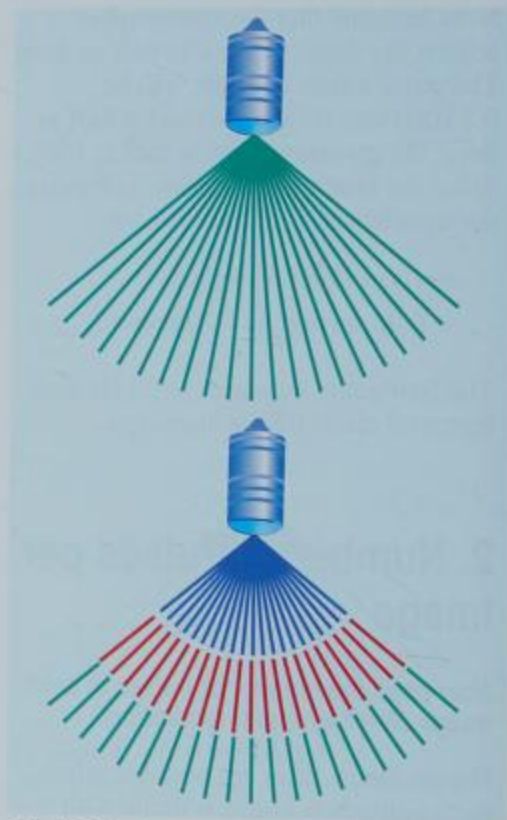


**Fig. 13.3** In this example, multi-focus (lower) requires three times the number of pulses for each image. Thus, the frame rate is less than that of single focus (upper).

**Table 13.3 Multi-focus and Temporal Resolution**

| Single Focus                 | Multi-focus                      |
|------------------------------|----------------------------------|
| • one pulse per scan line    | • many pulses per scan line      |
| • shorter $T_{\text{frame}}$ | • longer $T_{\text{frame}}$      |
| • higher frame rate          | • lower frame rate               |
| • better temporal resolution | • diminished temporal resolution |
| • poorer lateral resolution  | • improved lateral resolution    |

### Example

Assume that an ultrasound system creates an image with 100 penetration lines into the body. The system is single focus. Then, 100 distinct sound pulses create the image.

Now, imagine that the sonographer adjusts the system to operate with 4 foci. Since each focus requires its own sound pulse, four pulses are needed to create one scan line. So,  $4 \times 100$ , or 400 pulses are needed to create the image. This increases the time required to make each image. Therefore, frame rate and temporal resolution diminish with multi-focus.

### What is the main advantage of multiple focal zones?

Although multi-focusing has a negative effect on temporal resolution, it improves the accuracy of the individual images.

With multi-focus, each scan line has **better lateral resolution** because it is **narrow over a wide range of depths**. In deciding whether to use more than one focus, the sonographer must balance the trade-offs between temporal resolution and lateral resolution.

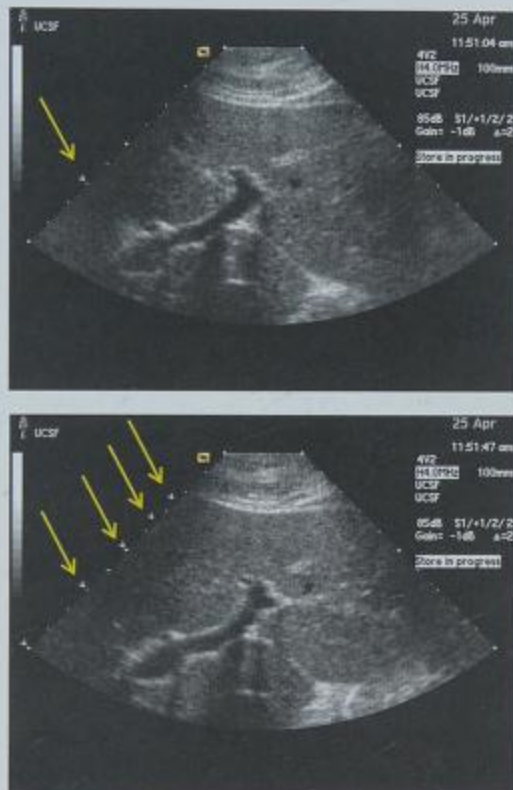


**Fig. 13.4** The upper image has a single focus. Multi-focusing in the lower image reduces frame rate. The yellow arrows identify the foci.



## Sector Size

When the sonographer expands the sector size (also called **field of view**), more pulses are required to create an image. Temporal resolution decreases (see Fig. 13.5 and Fig. 13.6).

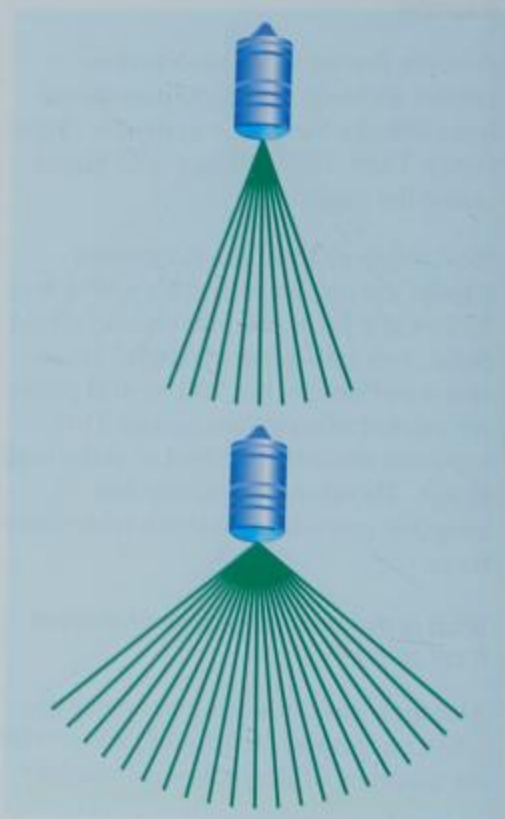


**Fig. 13.5** Field of view and frame rate are inversely related. Narrower images (upper) result in higher frame rates. Wider images (lower) result in lower frame rates.

**Table 13.4** Field of View and Temporal Resolution

| Narrow Sector                  | Wide Sector                    |
|--------------------------------|--------------------------------|
| • fewer pulses per frame       | • more pulses per frame        |
| • shorter $T_{\text{frame}}$   | • longer $T_{\text{frame}}$    |
| • higher frame rate            | • lower frame rate             |
| • superior temporal resolution | • inferior temporal resolution |

### Example

Let us assume that a system creates a 30-degree sector image with 1 transmit line for each degree of sector. In this case, each complete image will require 30 distinct sound pulses.

Now, imagine that the sonographer makes only one change and adjusts the system to create a 90-degree sector image. The image now requires 90 distinct sound pulses (1 per degree of sector size) and, therefore, more time to make the image. The frame rate decreases and temporal resolution is reduced.



**Fig. 13.6** Field of view and frame rate are inversely related. Narrower images (upper) result in higher frame rates. Wider images (lower) result in lower frame rates.

## Line Density

Although it is not always apparent, ultrasound systems can alter the spacing between sound beams. This is called **line density**.

Lines may be spaced far apart (low line density) or closely packed (high line density), as illustrated in Fig. 13.7. When line density is low, few pulses create each image and the frame rate is high. Temporal resolution is high (upper figure).

When line density is high, the number of pulses per image increases, frame rate drops, and the temporal resolution decreases (lower figure).

Some systems allow the sonographer to directly change the spacing, whereas others set the spacing automatically and do not require intervention by the sonographer.



**Fig. 13.7** Line density and frame rate are inversely related. Images with fewer lines result in higher frame rates (upper). Images with more lines result in lower frame rates (lower).



### Example

Assume that a system creates a 90-degree sector image with a line every 2 degrees. In this case, the image comprises 45 distinct sound pulses.

If the sonographer increases the line density to 1 line every degree (the sector size remains 90 degrees), then the number of pulses per image increases from 45 to 90. More time is needed to make the image, and the frame rate decreases. As a result, temporal resolution degrades.

### What is the main advantage of high line density?

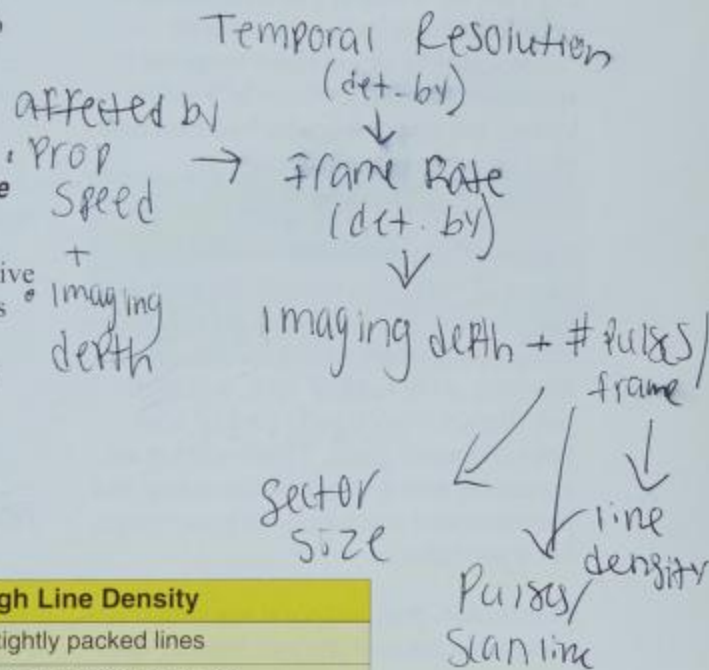
Although high line density has a negative effect on temporal resolution, the gaps between the lines are smaller. These smaller gaps improve the accuracy of each individual image.

With high line density, contains more detail, **improved spatial (de**

In deciding whether to increase line density, the sonographer must trade-offs between temporal resolution and spatial resolution.

Table 13.5 Line Density and Temporal Resolution

| Low Line Density             | High Line Density              |
|------------------------------|--------------------------------|
| • widely spaced lines        | • tightly packed lines         |
| • fewer pulses per frame     | • more pulses per frame        |
| • shorter $T_{\text{frame}}$ | • longer $T_{\text{frame}}$    |
| • higher frame rate          | • lower frame rate             |
| • high temporal resolution   | • low temporal resolution      |
| • poor spatial resolution    | • excellent spatial resolution |



## Line 5 About Temporal Resolution

*How are temporal resolution and image quality related?*

Understanding this question and its answer is important. There are many trade-offs in diagnostic ultrasound: we must decide which is more important—excellent image quality (a superior “photograph”), or excellent temporal resolution (a superior “movie”). Some system settings that produce an excellent photograph are inconsistent with producing an excellent movie!

Suppose that we want an outstanding image of a stationary structure, such as a gall bladder. To produce an exceptional image, our system would use multiple focusing, wide field of view, and high line density (very tightly packed scan lines and small gaps). These settings are consistent with a very low frame rate and poor temporal resolution—a great image, but a poor movie.

In this case, poor temporal resolution is acceptable because the gall bladder does not move. These settings are appropriate for scanning motionless organs.

In contrast, suppose that we want to accurately display the motion of a rapidly moving structure, such as a fetal heart. To produce exceptional temporal resolution, our system would use single focus, a narrow field of view, and low line density (scan lines spaced far apart). The resulting image contains much less information than that of the gall bladder described previously; however, these settings are consistent with a very high frame rate and exceptional temporal resolution—adequate images, but a great movie.

These two examples illustrate the trade-offs between image quality and temporal resolution: the factors that enhance one characteristic often compromise the other. The right choice depends on the clinical setting.

**Note:** Lateral resolution improves with multi-focusing.

Spatial resolution improves with higher line density.

## Summary: Temporal Resolution

Table 13.6 Operational Settings for Temporal Resolution

| Better—higher frame rate                                                                                                                      | Worse—lower frame rate                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• shallower imaging</li><li>• single focus</li><li>• narrow sector</li><li>• low line density</li></ul> | <ul style="list-style-type: none"><li>• deeper imaging</li><li>• multiple focal points (improves lateral resolution)</li><li>• wide sector</li><li>• high line density (improves spatial resolution)</li></ul> |



## Review: Real-Time Imaging

| Questions                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. Which of the following forms of resolution improve when frame rate increases?</p> <p>A. lateral<br/>B. longitudinal<br/>C. temporal<br/>D. spatial resolution</p>                                                                                                                         | <p>1. C. Temporal resolution is directly related to frame rate. Higher frame rates improve temporal resolution.</p>                                                                                                                                                                                  |
| <p>2. Which of the following is consistent with improved temporal resolution?</p> <p>A. color Doppler<br/>B. more gray shades<br/>C. more detail<br/>D. higher frame rate</p>                                                                                                                   | <p>2. D. Frame rate determines temporal resolution. High frame rates (lower <math>T_{\text{frame}}</math>) result in improved temporal resolution.</p>                                                                                                                                               |
| <p>3. All of the following decrease temporal resolution <i>except</i>:</p> <p>A. lower frame rate<br/>B. deeper imaging<br/>C. multi-focus<br/>D. narrower sector</p>                                                                                                                           | <p>3. D. Unlike the other choices, narrow sectors actually improve temporal resolution. Narrow sector images are created with fewer pulses than wide sector images.</p>                                                                                                                              |
| <p>4. A sonographer adjusts an ultrasound scan to double the depth of view from 5 cm to 10 cm. What happens to the frame rate?</p> <p>A. it is halved<br/>B. it doubles<br/>C. it increases from 5 to 10 Hz<br/>D. it is unchanged</p>                                                          | <p>4. A. The frame rate will be halved. Frame rate and imaging depth are inversely related. If nothing else is altered, the frame rate is halved when the imaging depth is doubled.</p>                                                                                                              |
| <p>5. A sonographer adjusts an ultrasound scan to double the depth of view from 5 cm to 10 cm. If the frame rate remains the same, which one of the following also occurs?</p> <p>A. increased line density<br/>B. wider sector<br/>C. multi-focus imaging turned on<br/>D. narrower sector</p> | <p>5. D. Narrower sector. This is the only choice that acts to make each image in less time. Since the imaging depth is increased, something else must have happened to counteract the increased time to create each image. Generally, creating an image with a narrower sector takes less time.</p> |

| Questions                                                                                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>6. A sonographer adjusts an ultrasound machine to change the sector size from 90 to 45 degrees. Nothing else changes. What happens to the frame rate?</p> <p>A. it is doubled<br/>B. it remains unchanged<br/>C. it is halved<br/>D. it is tripled</p>                                                          | <p>6. A. The frame rate is doubled since fewer pulses are needed to make the image.</p> <p>Since the question states that nothing else changes, the line density remains the same, and therefore, frame rate increases.</p>                                                                                                               |
| <p>7. A sonographer adjusts an ultrasound system to change the sector size from 90 to 45 degrees. The frame rate was unchanged. What else must have happened?</p> <p>A. temporal resolution was doubled<br/>B. sector size was doubled<br/>C. line density was doubled<br/>D. imaging depth was halved</p>         | <p>7. C. Since the frame rate is unchanged, the number of pulses per frame was also unchanged. If the sector size is reduced, some other factor must increase the number of pulses per image. The only answer that increases number of pulses per frame is choice C, line density was doubled.</p>                                        |
| <p>8. A sonographer, using a phased array ultrasound system, turns off the multi-focus feature. What is the most likely consequence of this action?</p> <p>A. frame rate decreases<br/>B. temporal resolution degrades<br/>C. imaging depth increases<br/>D. temporal resolution improves</p>                      | <p>8. D. Temporal resolution increases. Changing from multi-focus to single focus reduces the number of sound pulses required to make each image. As a result, the time required to make each frame is reduced, frame rate is increased, and temporal resolution improves.</p>                                                            |
| <p>9. A sonographer increases the line density from 1 line per degree of sector to 3 lines per degree of sector. What is the most likely consequence of this action?</p> <p>A. frame rate increases<br/>B. temporal resolution decreases<br/>C. imaging quality decreases<br/>D. temporal resolution increases</p> | <p>9. B. Temporal resolution decreases. Increasing line density from 1 to 3 lines per degree triples the number of pulses in each image. As a result, the time required to make each frame is lengthened, frame rate is reduced, and temporal resolution decreases. In this case, frame rate is reduced to 1/3 of its original value.</p> |

| Questions                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>10. A sonographer reduces the sector angle from 90 degrees to 30 degrees. At the same time, the ultrasound system automatically increases the line density from 1 line per degree to 2 lines per degree. No other changes are made. What will happen to the frame rate?</p> <p>A. increases<br/>B. decreases<br/>C. remains unchanged</p>      | <p>10. A. Frame rate will increase. At first, each image comprises a total of 90 sound pulses—one pulse for each of the 90 degrees of sector size. In the second scenario, each image comprises 60 sound pulses—2 pulses for each degree. Since the 30-degree sector image comprises fewer pulses, <math>T_{\text{frame}}</math> is reduced and frame rate increases.</p>                   |
| <p>11. A sonographer reduces the sector angle from 90 degrees to 30 degrees. At the same time, the ultrasound system automatically increases the line density from 1 line per degree to 3 lines per degree. No other changes are made. What will happen to temporal resolution?</p> <p>A. increases<br/>B. decreases<br/>C. remains unchanged</p> | <p>11. C. Temporal resolution is unchanged. At first, each frame comprises 90 sound pulses (one pulse per degree, 90 degrees). In the second scenario, 90 sound pulses are also needed to make each frame (3 pulses per degree, 30 degrees). Since the number of pulses per frame is unchanged, <math>T_{\text{frame}}</math> is unchanged, and thus, temporal resolution is unchanged.</p> |
| <p>12. Which of the following is most important in determining the frame rate of a system?</p> <p>A. speed of sound in the medium<br/>B. dynamic range of the receiver<br/>C. transducer frequency<br/>D. transmitter output</p>                                                                                                                  | <p>12. A. Of these choices, speed of sound in a medium is the most important factor in determining frame rate.</p>                                                                                                                                                                                                                                                                          |
| <p>13. Which of the following is most important in determining the frame rate of a system?</p> <p>A. depth of view<br/>B. dynamic range of the receiver<br/>C. transducer frequency<br/>D. transmitter output</p>                                                                                                                                 | <p>13. A. Of these choices, depth of view is the most important factor in determining frame rate.</p>                                                                                                                                                                                                                                                                                       |



| Questions                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>14. What is the frame rate if each image of the ultrasound system is created in 0.02 sec (1/50 sec)?</p> <p>A. 20 Hz<br/>B. 100 Hz<br/>C. 50 Hz<br/>D. 15 Hz</p>  | <p>14. C. Frame rate and <math>T_{\text{frame}}</math> are reciprocals. In other words, <math>T_{\text{frame}}</math> multiplied by the frame rate equals one. If the time to make a frame is one-fiftieth of a second, then the frame rate is 50 per second, or 50 hertz.</p> |
| <p>15. What is the time needed to make a single image if the frame rate of an ultrasound system is 20 Hz?</p> <p>A. 1 s<br/>B. 0.02 s<br/>C. 0.05 s<br/>D. 15 Hz</p> | <p>15. C. Frame rate and <math>T_{\text{frame}}</math> are reciprocals. In other words, <math>T_{\text{frame}}</math> multiplied by the frame rate equals one. If 20 frames are created each second, then <math>T_{\text{frame}}</math> is 1/20 or 0.05 second.</p>            |
| <p>16. True or False. The critical factor in determining frame rate, line density, and imaging depth is the transducer style.</p>                                    | <p>16. False. The critical factor in determining frame rate, line density, and imaging depth is time.</p>                                                                                                                                                                      |
| <p>17. True or False. The number of lines per frame and the frame rate determine the frequency.</p>                                                                  | <p>17. False. The number of lines per frame and the frame rate determine the pulse repetition frequency.</p>                                                                                                                                                                   |
| <p>18. True or False. The number of lines per frame and the frame rate determine the pulse repetition frequency.</p>                                                 | <p>18. True. The number of lines per frame and the frame rate determine the pulse repetition frequency.</p>                                                                                                                                                                    |
| <p>19. True or False. If the imaging depth of a scan is 15 cm and there are 100 lines in the image, then the number of pulses making up the scan is 1500.</p>        | <p>19. False. If the imaging depth of a scan is 15 cm and there are 100 lines in the image, then the number of pulses making up the scan is 100.</p>                                                                                                                           |
| <p>20. True or False. If the imaging depth of a scan is 15 cm and there are 100 lines in the image, then the number of pulses making up the scan is 100.</p>         | <p>20. True. If the imaging depth of a scan is 15 cm and there are 100 lines in the image, the number of pulses making up the scan is 100.</p>                                                                                                                                 |
| <p>21. True or False. If 100 scan lines make up an image and the frame rate is 30 per second, then the transducer's frequency is 3,000 Hz.</p>                       | <p>21. False. A transducer's frequency is independent of the characteristics of the image that it creates.</p>                                                                                                                                                                 |

| Questions                                                                                                                                                                      | Answers                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 22. True or False. If 100 scan lines make up an image and the frame rate is 30 per second, then the system's pulse repetition frequency is 3,000 Hz.                           | 22. True. Pulse repetition frequency is the number of pulses created per second. In this example, it is lines per image multiplied by frame rate.                                                |
| 23. When the frame rate is 30 Hz, how long does it take to create a frame?<br>A. 30 sec<br>B. 3 sec<br>C. 0.3 sec<br>D. 1/30 sec<br>E. 1/3 sec                                 | 23. D. Recall that frame rate and $T_{\text{frame}}$ are reciprocals. Thus, if the frame rate is 30 per second, the time to create each frame is one-thirtieth of a second.                      |
| 24. Under certain conditions, an ultrasound system creates each image in 0.01 seconds. What is the frame rate?<br>A. 1 Hz<br>B. 10 sec<br>C. 100 Hz<br>D. 200 Hz<br>E. 0.02 Hz | 24. C. Recall that frame rate and $T_{\text{frame}}$ are reciprocals. Thus, if the time required to make one frame is 0.01 seconds (one hundredth of one second), then the frame rate is 100 Hz. |
| 25. What is the fundamental limitation of temporal resolution?<br>A. imaging depth<br>B. speed of sound in the medium<br>C. line density<br>D. sector size                     | 25. B. Speed of sound in the medium is the fundamental limitation of temporal resolution.                                                                                                        |

## Pulsed Echo Instrumentation

An ultrasound system is highly sophisticated. It creates sound pulses, retrieves reflections, and presents audio and visual information for our interpretation.

The system has two major functions:

1. The **preparation and transmission** of electrical signals to the transducer, which creates a sound beam.
2. The **reception** of electrical signals from the transducer, with subsequent processing into clinically meaningful images and sounds.

The components of a typical ultrasound system are integrated so that sound pulses are transmitted and received and that information is accurately processed into images that provide meaningful diagnostic information.



Ultrasound systems contain these six major components:

1. **Transducer**—During transmission, the transducer transforms electrical energy into acoustic energy. During reception, it converts the returning acoustic energy into electrical energy.
2. **Pulser and Beam Former**—creates and controls the electrical signals sent to the transducer that generate sound pulses. The **pulser** determines the amplitude, pulse repetition period, and pulse repetition frequency, while the **beam former** determines the firing delay patterns for phased array systems.
3. **Receiver**—transforms the electrical signals from the transducer (produced by the reflected sound) into a form suitable for display.
4. **Display**—presents processed data. The display may be a flat screen monitor, a transparency, a spectral plot, or a variety of other formats.
5. **Storage**—archives the ultrasound studies. Typical storage devices (or **media**) include computer hard drives, CD, DVD, videotape, magneto-optical discs, paper printouts, photographs, and USB drives.
6. **Master Synchronizer**—maintains and organizes the proper timing and interaction of the system's components.

## Pulser

The pulser creates electrical signals that excite the transducer's PZT crystals and create sound beams. The pulser functions during transmission.

## Transducer Output

The sonographer can adjust the magnitude of the pulser's electrical voltage spike, which ranges from near 0 to approximately 100 volts.

Changes in pulser voltage modify the brightness of the entire image displayed on the system's screen.

When the pulser is set to a low voltage, the PZT (**active element** or **ceramic**) of the transducer vibrates gently, and a weak sound beam is transmitted into the body. The reflected echoes are weak, and the entire image tends to be dark (see Fig. 14.1, upper image).

When pulser voltage is high, the transducer's active element vibrates more forcefully, and transmits stronger sound beams into the body. The reflected echoes are stronger, and the entire image is brighter (see Fig. 14.1, lower image).



**Fig. 14.1** Changes in transducer output affect the brightness of the entire image. The upper image was created with a low output, while the lower image was created with a high output.

## Synonyms

Because there are no industry-wide standards for labeling ultrasound systems, **pulser voltage** is described by many different terms, such as **output gain, acoustic power, pulser power, energy output, transmitter output, power, or gain**. The term **gain** is particularly vague, and should be avoided.

Attempts to standardize transducer output have resulted in two measurements that appear on the screens of modern ultrasound systems: **Thermal Index (TI)** and **Mechanical Index (MI)**. These terms are discussed in Chapter 24, *Bioeffects*.

## Adjustable

**Yes**—the sonographer uses a control on the console to alter transducer output.

## Effect on Image

Modifying transducer output changes all the pulses transmitted to the body and as a result, all the reflections received from boundaries between anatomic structures. The brightness of the entire image changes.

Generally, as long as image quality is optimal, lower pulser voltages are desirable because they decrease transmitted acoustic energy and minimize patient exposure to ultrasonic energy. Lower pulser voltages minimize the likelihood of bioeffects.

**Note:** Output power alone cannot make an image of uniform brightness from top to bottom.



## What is *noise*?

Noise is loosely defined as a random and persistent disturbance that obscures or reduces a signal's clarity. Noise contaminates images with low-level, undesirable information.

### What is *signal-to-noise ratio*?

Signal-to-noise is a comparison of the meaningful information (**signal**) in an image, compared to the amount of contamination (**noise**).

- When the signal-to-noise ratio is **high**, the signal is much stronger than the noise and the image is of high quality (see Fig. 14.2, upper image).
- When the signal-to-noise ratio is **low**, the strength of the signal is closer to the strength of the noise. The image contains a larger amount of visible contamination, and has less diagnostic value (see Fig. 14.2, lower image).

### How does *transducer output* affect noise?

When transducer output is low, noise is more likely to degrade the image. As the sonographer **increases output power**, the **signal-to-noise ratio also increases**. The image quality improves as the signal dominates the image and the noise disappears. Because noise levels generally remain constant, **increasing output power is the most common way to improve (increase) the signal-to-noise ratio**.

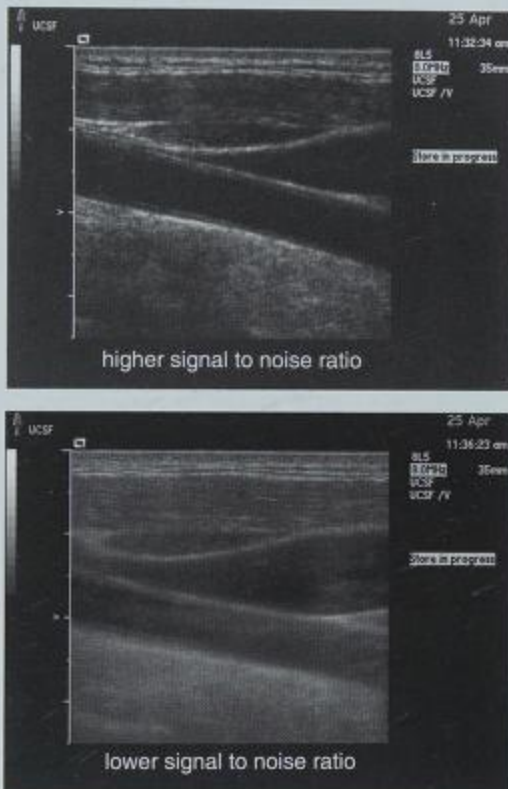


**Fig. 14.2** High vs. low signal-to-noise ratio. The upper image has a high signal-to-noise ratio; the signal dominates. The lower image has a low signal-to-noise ratio; there is much visible noise that degrades the image.

## Pulse Repetition Period

In addition to controlling the strength of the transmitted sound wave, the pulser determines the time between one voltage spike and the next, the **pulse repetition period** (PRP). Recall that PRP and pulse repetition frequency (PRF) are reciprocals. Thus, PRF is determined as well.

### Effect on Image

PRP determines the maximum imaging depth (also called **depth of view**).

When the PRP is short, the pulse repetition frequency is high, and the system spends less time listening. The result is superficial imaging (see Fig. 14.3, upper image).

When the PRP is long, the pulse repetition frequency is low and the system listens for a longer time. The imaging is deeper (see Fig. 14.3, lower image).

### Adjustable

**Yes**—the sonographer uses a control on the console to alter the depth of view.

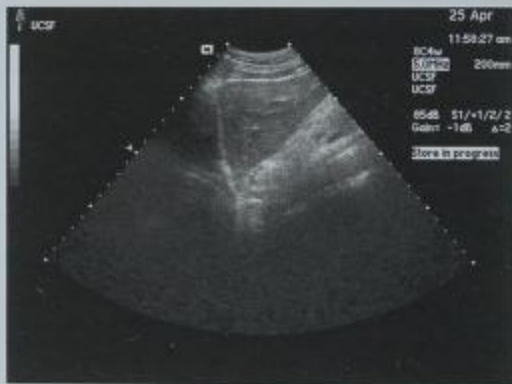


**Fig. 14.3** Changes in imaging depth are made by changing the pulse repetition period (PRP). The upper, shallow image is created with a shorter PRP. The lower, deep image is created with a longer PRP.

**Table 14.1** Depth of View

| Shallow Imaging             | Deep Imaging               |
|-----------------------------|----------------------------|
| • shorter listening time    | • longer listening time    |
| • shorter pulse rep. period | • longer pulse rep. period |
| • higher PRF                | • lower PRF                |

## Beam Former

Considered part of the transmitter, the **beam former** functions with array transducers during transmission and reception. The beam former is a sophisticated electronic device that receives the pulser's single electrical spike (Fig. 14.4, green arrow) and distributes it to the numerous active elements of an array transducer.

With phased, linear, annular, and convex array probes, the beam former coordinates the complex electrical signals sent to each active element, thereby optimizing the transmitted ultrasound beam. The beam former also adjusts electrical spike voltages to reduce lobe artifacts in a process called **apodization** (see page 193).

During reception, the beam former establishes the correct time delays used for dynamic receive focusing. Finally, the beam former controls dynamic aperture by varying the number of PZT crystals used during both reception and transmission (see page 194).

Modern beam formers use advanced microprocessor technology and produce signals in digital format. This state-of-the-art device is called a **digital beam former**.

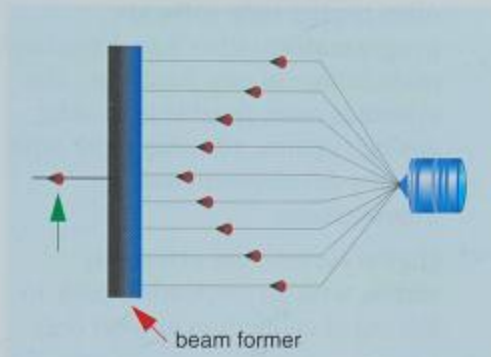


**Fig. 14.4** The beam former (red arrow) creates and distributes the delay patterns for array transducers during transmission.



Digital beam formers have several advantages:

- System modifications and updates often require only **software programming** rather than design and manufacture of new hardware. The system is more flexible than older analog systems, allowing more rapid product development and improvement.
- Digital systems are **extremely stable**, with no mechanical parts to fall out of calibration or wear out.
- Digital systems are **versatile**, capable of using transducers with a wide range of frequencies.

## Switch

The beam former has a special “transmit-receive” switch that is important during both transmission and reception.

During pulse creation, the voltages from the ultrasound system to the transducer are very high, whereas during reception, the voltages from the transducer back to the ultrasound system are extremely low.

The switch protects the delicate receiver components from the powerful signals that are created for pulse transmission (see Fig. 14.5). The switch also directs the electrical signals from the transducer to the appropriate electronic and processing components within the ultrasound system.

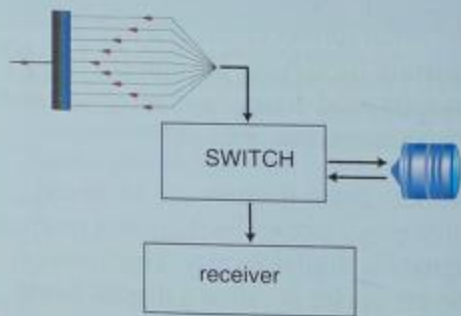


**Fig. 14.5** The switch protects the sensitive electrical components in the receiver from the high voltages created during transmission.

## What is a *channel*?

A **channel** is made up of a single PZT element in the transducer, the electronics in the beam former/pulser, and the wire that **connects** them. The number of elements in an array transducer that can be excited simultaneously is determined by the number of channels in the ultrasound system. Most systems have between 32 and 256 channels.

## Receiver

Small sound pulses reflect off a boundary within the body, return to the transducer, and strike the PZT crystals, generating tiny electrical signals. The receiver prepares the information contained in these minuscule signals for eventual display on the system's monitor.

## Order of Receiver Operations

These five operations must be performed in the appropriate order for the system to function properly:

1. amplification
2. compensation
3. compression
4. demodulation
5. reject

**Note:** It is easy to remember the proper sequence of receiver functions since the order is alphabetical.

## 1. Amplification

The first function of the receiver is **amplification**, also called **receiver gain**. In the amplification process, each electronic signal returning from the transducer is made larger. Each signal undergoes an **equal amount** of amplification.

Amplification is required because the electrical signals are too low to be displayed on the monitor.

### Effect on Image

All electrical signals in the receiver are affected **identically** by amplification. The entire image is made brighter or darker when the sonographer adjusts that receiver gain (see Fig. 14.6).

Handwritten note: *overall brightness*

Amplifiers cannot distinguish between reflections that provide meaningful diagnostic information (signal) from the accompanying noise that degrades image quality. Amplification thus *does not* improve signal-to-noise ratio, since both signal and noise are amplified equally.

**Note:** Amplification alone cannot make an image of uniform brightness from top to bottom.

### Adjustable

**Yes**—the sonographer uses a control on the system console to alter amplification.

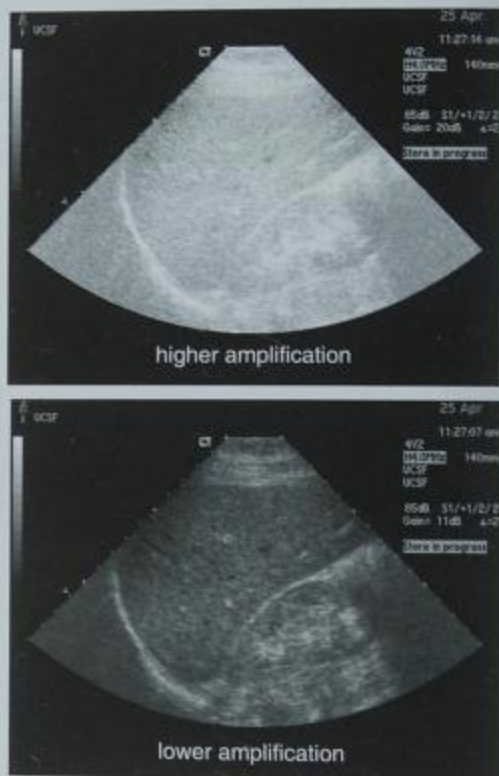


**Fig. 14.6** Changes in amplification or receiver gain alter the brightness of the entire image. The upper image results from high amplification levels, while the lower image was created with less amplification. Unlike output power, patient exposure levels to ultrasonic energy are not altered when the sonographer changes amplification.



## Units

Amplification is often measured with units of **decibels** (dB), which are **relative** units of measure. The final signal (leaving the receiver) is compared to the initial signal strength (entering the receiver).

## Typical Values

From 60 to 100 dB.

*What is preamplification?*

*What is its role in processing signals from the transducer during reception?*

**Preamplification** is the process of improving the quality of a signal before it is amplified. Preamplification occurs as close to the active elements as is practical, often **within the transducer** itself.

Preamplifiers are specially designed to prevent electronic noise from contaminating the tiny (yet meaningful) electrical signals created by the transducer's active elements during reception.

## 2. Compensation

The second function of the receiver is compensation. Sound waves attenuate (weaken) as they travel. Without compensation, every ultrasound image would become progressively darker with increasing depth (see Fig. 14.7, upper image). Furthermore, if two identical structures are located at different depths, the deeper one appears darker than the shallower one. The receiver corrects for attenuation with a process called **compensation**.

Compensation creates an image that is **uniformly bright from top to bottom**. In a properly compensated image, a pair of identical reflectors at different depths are displayed with the same brightness (see Fig. 14.7, lower image).



**Fig. 14.7** Without proper compensation, images become increasingly dark with depth (upper image). Proper compensation creates images of uniform brightness at all depths (lower image).

### Adjustable

**Yes**—the sonographer can adjust compensation. The controls for compensation may appear as a series of slider bars or a collection of three knobs on the console (see Fig. 14.8). Newer systems also have an automated compensation feature.

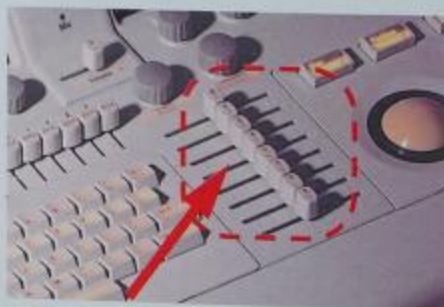


**Fig. 14.8** Compensation controls on a system console.

## Units

Compensation is a form of variable amplification, and therefore is measured with the same relative units as amplification, decibels (dB).

## Effect on Image

Compensation treats echoes differently, depending upon the depth from which they arise.

For example, three identical masses located in the body at depths of 2 cm, 4 cm, and 6 cm will produce reflections with different strengths. The echo will be strongest from the mass at 2 cm and weakest from the mass at 6 cm; the echo from the mass at 4 cm will have intermediate strength. Echoes arising from greater depths are weaker because sound beams attenuate the farther they travel.

For diagnostic accuracy, these three reflectors must appear identically on the final image. The function of compensation is to produce an image of uniform brightness from top to bottom.

## Synonyms

Compensation is also known as **time-gain compensation (TGC)**, **depth gain compensation (DGC)**, and **swept gain**.



## Anatomy of a TGC Curve

In a typical TGC curve, illustrated in Fig. 14.9, the x-axis indicates the amount of compensation. The y-axis indicates the reflector depth (starting at skin level and extending deeper).

At superficial depths, reflections undergo a small, constant amount of compensation called the **near gain**.

The depth at which variable compensation begins is known as the **delay**.

In the region of the **slope**, compensation corrects for the effects of increasing attenuation that result from increasing path length.

At the depth of the **knee**, reflections are maximally compensated by the ultrasound system.

The **far gain** indicates the maximum amount of compensation that the receiver can provide.

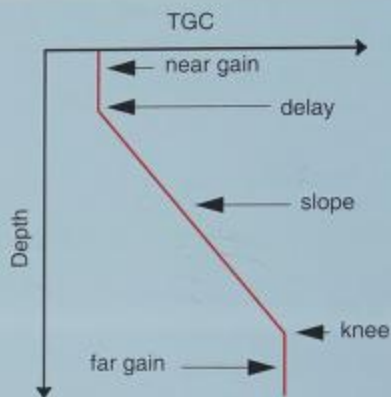


Fig. 14.9 A typical TGC, or time gain compensation curve. The x-axis is TGC and the y-axis is depth.



Fig. 14.10 Typical compensation settings on a system console.

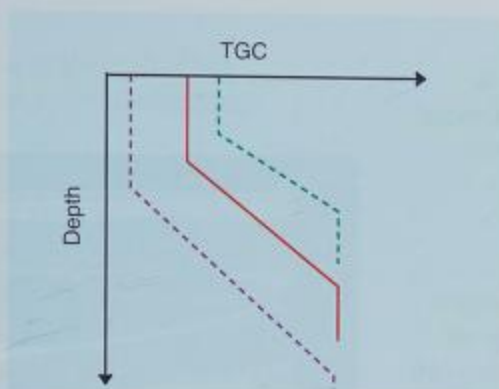


Fig. 14.11 Use this illustration to answer the questions that follow.

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. You are using a 4 MHz transducer and have adjusted the time gain compensation (TGC) perfectly, as represented by the red TGC line. You are given a new transducer with an unknown frequency. The TGC is then adjusted to create the same image as that obtained using the 4 MHz transducer—this new TGC setting is the purple dotted line. Is the frequency of the new transducer greater than or less than 4 MHz? Why?</p> | <p>1. The new transducer's frequency is less than 4 MHz. The delay is deeper with the new transducer. In addition, at any particular depth in the region of the "slope," less compensation is applied when using the new transducer.</p> <p>Recall that compensation is used to "make up for" or "pay back" attenuation. In this example, the shift of the TGC curve downward and to the left indicates there was less attenuation. Less attenuation occurs with lower frequency transducers.</p> |
| <p>2. You are using a 4 MHz transducer and have adjusted the time gain compensation (TGC) perfectly, as represented by the red TGC line. You are given a new transducer with an unknown frequency. The TGC is then adjusted to create the same image as that obtained using the 4 MHz transducer—this new TGC setting is the green dotted line. Is the frequency of the new transducer greater than or less than 4 MHz? Why?</p>  | <p>2. The new transducer's frequency is higher than 4 MHz. Notice that the TGC curve is shifted upward and toward the right for the new transducer. The delay is shallower. At any particular depth in the region of the "slope," extra compensation is applied when using the new transducer.</p> <p>More attenuation occurs with higher frequency transducers; in this case, one that exceeds 4 MHz.</p>                                                                                        |

### 3. Compression

The third function of the receiver is compression. Compression is performed twice. First, compression keeps the electrical signal levels within the accuracy range of the system's electronics.

Second, compression keeps an image's gray scale content within the range of detection by the human eye. Humans can distinguish approximately 20 shades of gray, and compression allows us to visualize different tissues within these 20 gray shades.

Compression is performed without altering the ranking between the signals; the largest signal remains largest, and the smallest signal remains smallest. The mathematics of compression are discussed in Chapter 16, *Dynamic Range*.

#### Adjustable

**Yes**—ultrasound systems usually have two kinds of compression: one that is integral to the system design and cannot be changed, and another that is **user adjustable**. User-controlled compression modifies the **gray scale mapping** of ultrasound images (see Fig. 14.12).

#### Effect on Image

Compression changes the gray scale characteristics of the image.

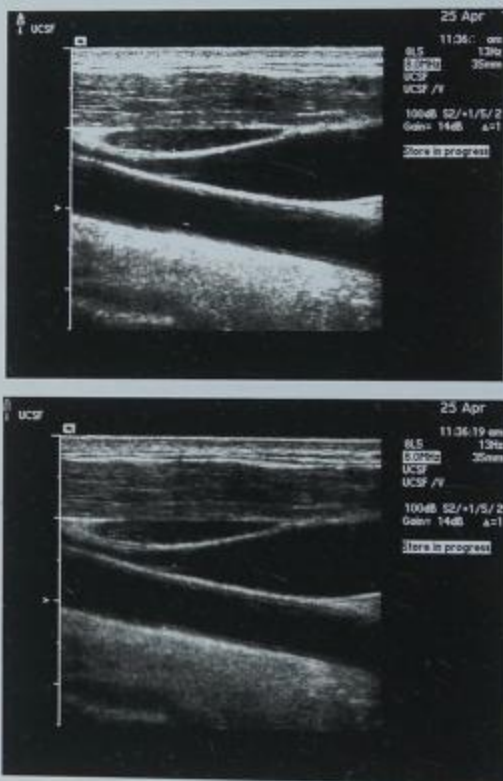


Fig. 14.12 Compression alters the gray scale mapping of an ultrasound image.



## Synonyms

Compression is also called **log compression**, or **dynamic range**.

## Units

Compression is often reported in units of decibels, or **dB**. The decibel is a relative unit that compares one signal to another.

## More about Compression

### *Why is log compression important in clinical ultrasound?*

Log compression is an adjustable compression where **small differences in weak signals** are displayed and seen as different gray scale levels. However, a **wide range of strong signals** are all displayed as bright white.

Log compression is important clinically because most meaningful backscattered signals from biologic tissues are very weak and the sonographer must be able to see differences in these weak reflections.

On the other hand, comparisons of different strong reflections (strong, very strong, or exceedingly strong) are not as important clinically since they are unlikely to arise from biologic tissues that are different.

## 4. Demodulation

The fourth function of the receiver is demodulation. Demodulation is a two-part process that changes the electrical signals within the receiver into a form more suitable for display on a monitor.

**Rectification** converts all negative voltages into positive voltages. It corrects for, or eliminates, negative voltages (see Fig. 14.13).

**Smoothing** (or **enveloping**) places a smooth line around the “bumps” and evens them out (see Fig. 14.14).

### Adjustable

**No**—demodulation is built into the ultrasound system, and the sonographer cannot adjust it.

### Effect on Image

**None**—demodulation has no visible effect on the ultrasound image. The purpose of demodulation is to **change the form** of the electrical signal so that it is appropriate for the system’s display.

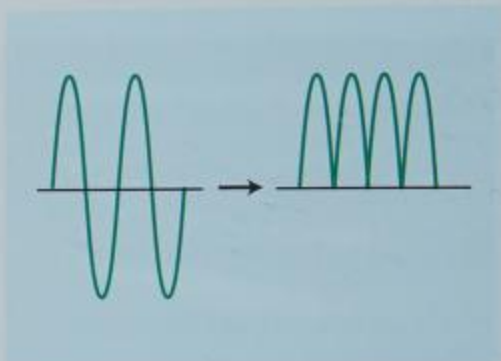


**Fig. 14.13** Rectification changes the form of the electrical signal by eliminating or correcting for negative voltages.

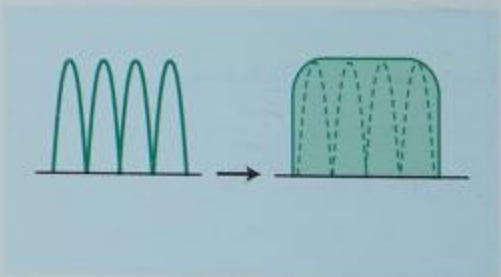


**Fig. 14.14** Smoothing eliminates the small “bumps” in the voltage signal.

## 5. Reject

The fifth function of the receiver is reject. Very low-level signals on the display may be associated either with meaningful diagnostic information or with meaningless noise.

Reject allows the sonographer to control whether low-level gray scale information within the data will appear on the displayed image.

It is desirable to display low-level reflections that contain meaningful information. On the other hand, low-level noise should not appear on the image.

### Synonyms

Reject is also called **threshold** or **suppression**.

### Adjustable

**Yes**—most ultrasound systems have two levels of reject: one that is built into the design of the system, and therefore, cannot be changed. The other is **user adjustable**.

### Effect on Image

Rejection affects all low-level signals on the image, regardless of their location. Rejection does not affect bright echoes (see Fig. 14.15).



**Fig. 14.15** Without reject, very faint reflections appear on the displayed image (upper). With reject, the weak reflections are eliminated from display (lower). Note that the bright reflections in both images are identical.



Table 14.2 Receiver Functions

| Function             | Adjustable | Signals Processed                                            | Effect on Image                                    |
|----------------------|------------|--------------------------------------------------------------|----------------------------------------------------|
| <b>Amplification</b> | Yes        | All signals treated identically.                             | Entire image gets brighter or darker.              |
| <b>Compensation</b>  | Yes        | Signals treated differently based on reflector depth.        | Image will be uniformly bright from top to bottom. |
| <b>Compression</b>   | Yes        | Signals treated differently depending on strength.           | Changes gray scale mapping.                        |
| <b>Demodulation</b>  | No         | Prepares electrical signals to be suitable for display.      | None.                                              |
| <b>Reject</b>        | Yes        | Only weak signals affected; strong signals remain unchanged. | Weak echoes appear or are eliminated from image.   |

## Dynamic Frequency Tuning

Recall that pulses used for imaging must be short to provide good axial resolution. The damping material helps to create short pulses (see page 117). As a result of damping, sound pulses used for imaging contain a wide range of frequencies and are described as **wide bandwidth**, or **broadband**.

Systems with dynamic frequency tuning use only the high frequency part of the reflected pulse's bandwidth to create the **superficial portion** of the image because higher frequency sound has superior axial resolution. The lower frequency portion of the bandwidth is used to create deeper portions of the image because they are the only frequencies that remain.

The higher frequency components have disappeared at great depths as a result of attenuation.

### Example: Dynamic Frequency Tuning

A pulse from a 5 MHz transducer may contain sound energy at frequencies ranging from 3 to 7 MHz. The receiver processes sound at the higher frequencies (6–7 MHz) from superficial reflectors and at the middle frequencies (4–6 MHz) from intermediate depth reflectors. Lower frequency sound (3–4 MHz) is used for deeper reflectors. Thus, the image quality in the superficial region is improved with dynamic frequency tuning.

Not all ultrasound systems have this feature.

## Output Power vs. Receiver Gain

Two sonographer-controlled settings, output power and receiver gain, modify the brightness of the entire image.

*What is the difference between output power and receiver gain? Why is it important to appreciate this difference?*

### Output Power

Output power affects image brightness by altering the strength of the sound pulse that the transducer sends to the body.

When the pulse is more powerful, all the returning echoes from the body are stronger, and the entire image is brighter. When the image is too bright because of elevated output power, the reflectors bloom, causing lateral and axial resolution to degrade.

When an image is too dark, increasing the output power creates a brighter image. Increasing output power **improves the signal-to-noise ratio** because the meaningful diagnostic echoes become stronger while the noise level remains unchanged.

### Receiver Gain

**Receiver gain** (also called **amplification**) alters the strength of the voltages in the receiver that the transducer created during reception. Higher amplification creates a brighter image; lower

amplification creates a darker image. Increasing amplification **does not alter the signal-to-noise ratio** since both the meaningful signals and the noise are treated identically.

### Patient Exposure to Ultrasound

The most important distinction between output power and amplification relates to bioeffects. **Patient exposure to sound energy is affected by alterations in output power** but not by changes in amplification.

### ALARA

When an entire image is too bright or too dark, adjustments to either output power or receiver gain will correct the problem.

*Which adjustments should be made first, and why?*

The rule is based on the bioeffects principle known as ALARA.

The **ALARA Principle**—As Low As Reasonably Achievable—states that when modifications to either output power or receiver gain can improve the image's diagnostic quality, the first and best choice is the one that will **minimize the patient's ultrasound exposure**.

- If the image is too dark, first increase the receiver gain, which does not increase patient exposure.
- If the image is too bright, first decrease the output power, which decreases patient exposure.

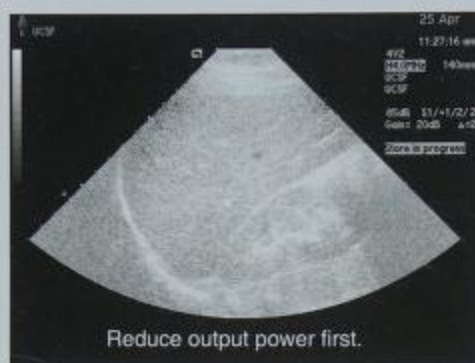


**Fig. 14.16** Patient exposure to ultrasound, ALARA, determines whether to first adjust output power or receiver gain.

**Table 14.3** Output Power vs. Receiver Gain

| Output Power                                 | Receiver Gain                              |
|----------------------------------------------|--------------------------------------------|
| • changes brightness of entire image         | • changes brightness of entire image       |
| • alters signal-to-noise ratio               | • does not affect signal-to-noise ratio    |
| • alters patient exposure                    | • does not change patient exposure         |
| • bioeffect concerns                         | • no bioeffect concerns                    |
| • decrease this first if image is too bright | • increase this first if image is too dark |

## Review: Pulsed Echo Instrumentation

| Questions                                                                                                                                                                                       | Answers                                                                                                                                                                                                               |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. All of the following are components of an ultrasound system <i>except</i>:</p> <p>A. transducer      D. pulser<br/>B. alternator      E. synchronizer<br/>C. display      F. receiver</p> | <p>1. B. An alternator is not a component of an ultrasound system.</p>                                                                                                                                                |
| <p>2. This type of pulser generates a constant electrical signal in the form of a sine wave:</p> <p>A. pulsed wave, array<br/>B. continuous wave<br/>C. pulsed wave, single crystal</p>         | <p>2. B. The pulser from a continuous wave ultrasound system creates a continuous electrical signal. The electrical signal's frequency determines the frequency of the continuous wave ultrasound (see page 122).</p> |



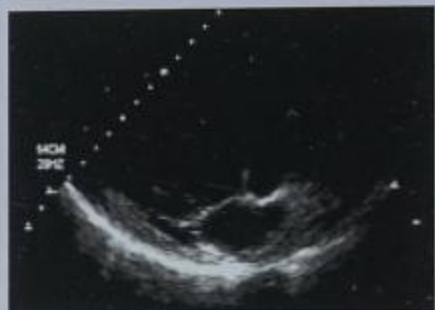
| Questions                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>3. This type of pulser generates a single electrical spike, which ultimately creates a single sound pulse:</p> <p>A. pulsed wave, phased array<br/>B. continuous wave<br/>C. pulsed wave, single crystal</p>     | <p>3. C. The pulser of a single crystal pulsed wave system creates a single electrical signal that excites the transducer to create a single acoustic pulse.</p>                                                         |
| <p>4. This type of pulser generates numerous electrical spikes, which ultimately create a single sound pulse:</p> <p>A. pulsed wave, phased array<br/>B. continuous wave<br/>C. pulsed wave, single crystal</p>     | <p>4. A. With phased array technology, the pulser emits numerous electrical spikes that excite numerous crystals in the array. However, only a single acoustic pulse is created from the multiple electronic spikes.</p> |
| <p>5. The acoustic power of a sound beam emitted from a transducer is determined by the _____ of the pulser's signal.</p> <p>A. pulse repetition frequency<br/>B. frequency<br/>C. voltage<br/>D. rectification</p> | <p>5. C, voltage.</p>                                                                                                                                                                                                    |
| <p>6. All of the following are functions of the receiver <i>except</i>:</p> <p>A. demodulation      C. amplification<br/>B. suppression      D. attenuation</p>                                                     | <p>6. D, attenuation.</p>                                                                                                                                                                                                |
| <p>7. Place these functions in the order in which the ultrasound system performs them:</p> <p>A. reject<br/>B. demodulation<br/>C. amplification<br/>D. compression<br/>E. compensation</p>                         | <p>7. C, E, D, B, A</p> <p>Hint: the order is alphabetical.</p>                                                                                                                                                          |
| <p>8. True or False. Amplification processes all reflected signals in a similar manner.</p>                                                                                                                         | <p>8. True. During amplification, all signals are processed identically.</p>                                                                                                                                             |
| <p>9. True or False. Compensation processes all reflected signals in a similar manner.</p>                                                                                                                          | <p>9. False. Those reflections arising from shallow structures are barely compensated. Those arising from deep structures are substantially compensated.</p>                                                             |

## Questions

### What should you do?

1. Which of the following choices is best when the image on your ultrasound system displays reflectors only in a region far from the transducer but no reflectors in a region close to the transducer?

A. adjust the system's compensation  
 B. use a higher frequency transducer  
 C. decrease the output power  
 D. adjust the reject level



2. Which of the following choices is best when the image on your ultrasound system is saturated (too bright everywhere)?

A. decrease the amplification or gain  
 B. use a higher frequency transducer  
 C. decrease the output power  
 D. adjust the reject level



3. Which of the following choices is best when the image on your ultrasound system displays only reflectors in a region close to the transducer but no reflectors that are deep?

A. adjust the system's compensation  
 B. use a higher frequency transducer  
 C. increase the output power  
 D. adjust the reject level



**Answers: 1. A, 2. C, 3. A**

# Displays and Image Processing

The display is the essential link between the ultrasound system and the medical staff. What we see ultimately determines what we conclude. Advances in display and storage technology have improved the utility of diagnostic sonography.

Modern flat panel computer monitors use advanced materials that create lightweight, thin displays. These newer display technologies are desirable since they provide higher frame rates with more lines per image when compared to traditional televisions. Flat panel displays have rendered traditional televisions virtually obsolete.

## Bistable vs. Gray Scale Displays

The prefix “bi-” means 2. Thus, bistable images are composed of only 2 shades: **black** and **white** (see Fig. 15.1A).

Gray scale displays present multiple levels of brightness (white, light gray, medium gray, etc.). The numerous levels allow the system to assign different gray shades to different echo amplitudes and to differentiate biologic tissues of different reflectivity (Fig. 15.1B).



## Display Controls

Two user controls on video monitors can alter characteristics of displayed images.

1. **Contrast** determines the range of brilliancies within the displayed image. Bistable images, in which only white and black appear, are high contrast (see Fig. 15.1).

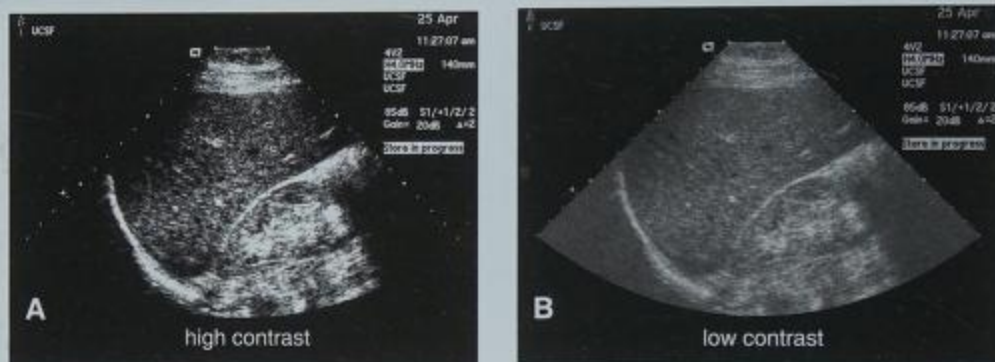


**Fig. 15.1** Variations in the contrast of ultrasound images. Image A on the left is high contrast (bistable), whereas image B on the right is low contrast (many gray shades).

2. **Brightness** determines the brilliance of the displayed image (see Fig. 15.2).

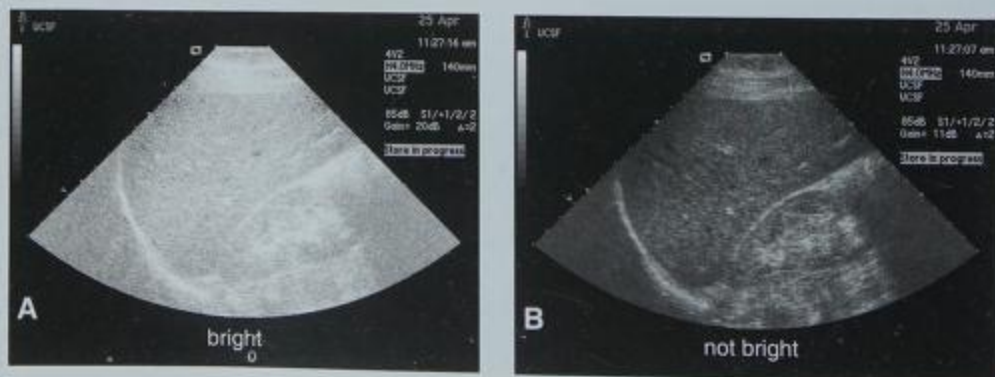


**Fig. 15.2** Variations in the brightness of ultrasound images. Image A is bright, whereas image B is not.

## Scan Converters

Gray scale imaging was initially made possible with the use of **scan converters**, which first store information and later display it. Storage of the image information in the scan converter is called “writing.” Later, image data is “read” from the scan converter for display on the monitor.

The scan converter changes the format of data. Ultrasound information is obtained from pulses emitted by a transducer that penetrate into the body. Multiple penetrations, or spokes, are needed for each two-dimensional image. However, monitors display video information as horizontal lines. **The scan converter translates the information from the spoke format into the video format** (see Fig. 15.3).

The data stored in the scan converter can be altered between the writing process and the reading process. For example, a black-on-white image can be inverted and turned into a white-on-black image.

In the early days of two-dimensional imaging, scan converters were constructed from analog technology. Modern **digital scan converters** use computer technology.

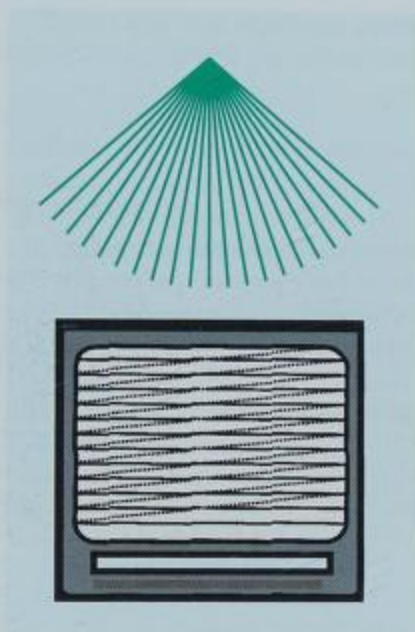


**Fig. 15.3** Ultrasound data is acquired from penetrations into the body (upper). Video is presented as horizontal lines (lower). The scan converter converts the penetration pattern into a horizontal line pattern.

## Analog vs. Digital Numbers

**Analog numbers** are “real world” numbers that are found in our everyday lives.

Examples of analog numbers include your weight or the length of a piece of string. Analog numbers can have an unlimited and **continuous range of values**. For example, the weight of a person may be 164 pounds, 163.998673 pounds, 164.004432 pounds, and so on.

**Digital numbers** are associated with computer devices. An individual's weight can also be measured with a digital device. However, digital numbers have only **discrete values**.

For example, a weight on a digital scale may be limited to whole pounds. With a digital scale, a person who actually weighs 163.12 pounds will be reported as weighing 163 pounds. Similarly, a person who actually weighs 163.48 pounds will also be reported as weighing 163 pounds.

Table 15.1 Analog vs. Digital Numbers

| Analog Numbers           | Digital Numbers   |
|--------------------------|-------------------|
| • real world             | • computer world  |
| • unlimited # of choices | • limited choices |
| • continuous values      | • discrete values |



## Analog Scan Converter

The analog scan converter was the first type of scan converter and made gray scale imaging possible.

The analog scan converter is a funnel-shaped vacuum tube with an electron gun located within its smaller end. A stream of charged particles, called **electrons**, contain the image information, and are shot out of the electron gun. The larger end of the tube contains a **dielectric matrix** or **silicon wafer**. The electrons strike the matrix where they are stored.

The dielectric matrix may be thought of as a picture divided into millions of tiny dots, each containing an electrical storage element (or *electron bucket*). The stored electron charges in each bucket are read to retrieve the image information.

The **spatial resolution**, or image detail, of an analog scan converter is excellent because of the large number of storage elements within the matrix.

**Hint:** Spatial resolution is “image detail.”

## Limitations of analog scan converters

Analog scan converters are now obsolete because of the following limitations:

- **Image fade**—stored charges on the silicon wafer dissipate over time.
- **Image flicker**—caused by switching between read and write modes.
- **Instability**—picture quality depends on many factors including length of use, room temperature, and humidity.
- **Deterioration**—image degrades as the device ages.

## Digital Scan Converter

Digital scan converters use computer technology to convert images into numbers, a process called **digitizing**. The image is stored in computer memory as a series of zeroes and ones. The numerical representation of the image is processed and then re-translated into an image displayed on a monitor.

## Advantages of digital scan converters

- **Uniformity**—consistent gray scale quality throughout the image.
- **Stability**—does not fade or drift.
- **Durability**—not affected by age or heavy use.
- **Speed**—nearly-instant processing.
- **Accuracy**—error-free.

Two important elements of digital scan converters are:

1. pixel
2. bit

## 1. Pixel

### Pixel

From the term *picture element*, the pixel is the smallest building block of a digital picture. When a picture is divided into a grid (similar to a checkerboard), each individual box is a pixel. At any instant in time, the entire pixel is a single shade of gray (see Fig. 15.4).



Fig. 15.4 Pixels, little square boxes, are the smallest element of a digital image.

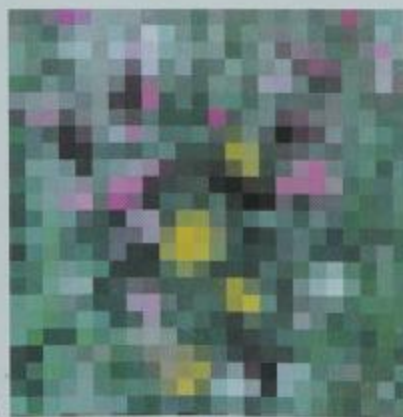
### Pixel Density

**Pixel density** is the number of picture elements per inch.

Higher pixel density is achieved with smaller pixels. In this case, more pixels are required to create the image. **Spatial resolution** improves with high pixel density and creates an image with greater detail (see Fig. 15.5B).

Table 15.2 Pixel Density

| Low Pixel Density          | High Pixel Density          |
|----------------------------|-----------------------------|
| • few pixels per inch      | • many pixels per inch      |
| • larger pixels            | • smaller pixels            |
| • less detailed image      | • more detailed image       |
| • lower spatial resolution | • higher spatial resolution |



A



B

Fig. 15.5 Image A has large pixels and a low pixel density. Image B, on the right, has smaller pixels and a high pixel density. More detail and improved spatial resolution are associated with higher pixel density.

## 2. Bit

### Bit

The word **bit**, derived from the term “**binary digit**,” is the smallest amount of computer memory.

A bit is *bistable*, having a value of either 0 or 1.

A **binary number** is a group of bits and is simply a series of zeroes and ones, such as 0101010011. Digital (or computer-based) numbers are binary.

Binary numbers are based on only two choices, 0 or 1. **Decimal numbers**, which are used in everyday life, are based on ten choices, 0 through 9.

A **byte** is a group of eight bits of computer memory, such as 10011111.

A **word** of computer memory consists of two bytes, or 16 bits.

Each pixel's shade of gray is determined by the cluster of bits assigned to it. With increasing numbers of bits per pixel, more shades of gray appear on the image. Images with many gray shades have better **contrast resolution**. (See Fig. 15.6).

16 bit = 2 bytes = 1 word

Table 15.3 Bits per Pixel

| Fewer Bits per Pixel                                                           | More Bits per Pixel                                                            |
|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• fewer shades of gray</li></ul>         | <ul style="list-style-type: none"><li>• more shades of gray</li></ul>          |
| <ul style="list-style-type: none"><li>• degraded contrast resolution</li></ul> | <ul style="list-style-type: none"><li>• improved contrast resolution</li></ul> |



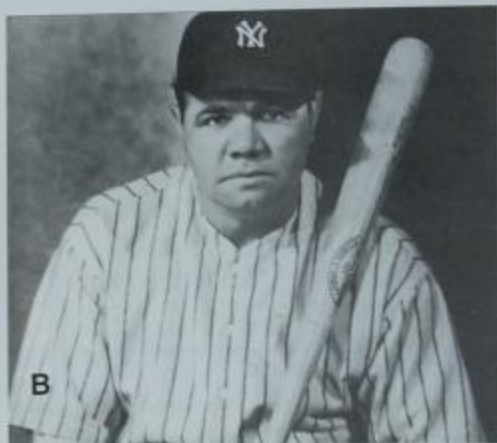


**Fig. 15.6** Image A, on the left, has few bits assigned to each pixel and produces fewer shades of gray. Image B has many bits assigned to each pixel, producing many shades of gray. Improved contrast resolution is associated with additional bits.

### Calculating the number of gray shades

To determine the number of gray shades that can be represented by a cluster of bits, multiply the number 2 by itself the same number of times as there are bits:

$$2^{\text{number of bits}} \quad \text{or} \quad 2^n$$

The result is the maximum number of different gray shades.

#### Example

How many possible shades of gray are displayed with 5 bits of memory?

Multiplying 2 by itself 5 times yields:

$$2 \times 2 \times 2 \times 2 \times 2 = 32$$

Thus, a maximum of 32 different gray shades can be displayed with 5 bits.

**Table 15.4** Bits and Shades of Gray

| # of bits | Exponent | Number of Shades                               |
|-----------|----------|------------------------------------------------|
| 1         | $2^1$    | 2                                              |
| 2         | $2^2$    | 4 ( $2 \times 2$ )                             |
| 3         | $2^3$    | 8 ( $2 \times 2 \times 2$ )                    |
| 4         | $2^4$    | 16 ( $2 \times 2 \times 2 \times 2$ )          |
| 5         | $2^5$    | 32 ( $2 \times 2 \times 2 \times 2 \times 2$ ) |
| 10        | $2^{10}$ | 1024                                           |
| n         | $2^n$    |                                                |

:

**Table 15.5** Digital Images: Pixels and Bits

| Pixels               | Bits                  |
|----------------------|-----------------------|
| • image element      | • computer memory     |
| • image detail       | • gray shades         |
| • spatial resolution | • contrast resolution |

## Analog and Digital Image Data

During reception, a transducer produces very low-voltage electrical signals that ultimately create an image. These signals are so weak that they are susceptible to contamination by electrical noise.

Converting information from analog to digital form is advantageous because digital information is far less susceptible to contamination. Prior to display on an analog monitor, the digital information must be converted back to analog form.

## Analog and Digital Image Information

Translating image information from the real world (**analog**) to the computer world (**digital**) and back again is a five-step process (see Fig. 15.7):

1. Electrical signals created by the transducer during reception are converted from analog to digital form by the **analog-to-digital (A-to-D) converter**. The digital information is a string containing only 0s and 1s.
2. The digital information is stored in the scan converter's computer memory. Any processing of the reflected signals before storage is called **preprocessing**.

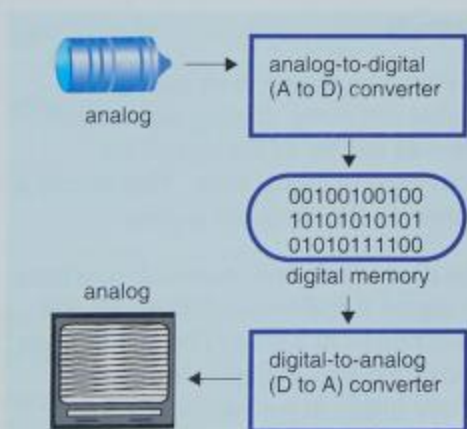


**Fig. 15.7** Analog signals from the transducer are changed to digital form and stored in computer memory. The digital signals are converted back into analog form for display on a standard television screen.

3. The image information, still in digital form, continues to be processed by the ultrasound system's computer. Any processing after storage in the digital scan converter is called **postprocessing**.
4. Digital signals cannot be directly displayed on analog display devices. The digital signals must be translated back into analog form by a **digital-to-analog (D-to-A) converter**.
5. The signal, now in analog form, is presented on the analog **video display** for interpretation.

Modern flat-panels are digital display devices. When using a digital display device, step 4, digital-to-analog conversion, is unnecessary.

### **Example**

A computer mouse is an analog-to-digital converter. Analog signals in the form of motion of the mouse are converted to digital form. This moves a cursor on the computer screen.

An iPod is a digital-to-analog converter. A digital file composed of zeroes and ones represent a song. The numbers are converted into analog voltages that create music in our earphones.

**Note:** The real world is analog.  
The computer world is digital.

- To move information from the real world (analog) to the computer world (digital), requires a translator, called an **analog-to-digital** or **A-to-D converter**.
- To move information from the computer world (digital) back to the real world (analog), requires a translator, called a **digital-to-analog** or **D-to-A converter**.



## Pre and Post Processing

### Preprocessing

is the manipulation of image data **before storage** in the scan converter. The sonographer controls preprocessing. Preprocessing alters the image data forever and cannot be reversed or undone.

### Postprocessing

is the manipulation of image data **after storage** in the scan converter. The sonographer controls postprocessing. Since postprocessing occurs after A-to-D conversion (digitization) and storage, all postprocessing changes can be reversed, which will restore the initial numerical values of the image data. Any alterations to a frozen image must be postprocessing.

Table 15.6 Pre and Post Processing

| Preprocessing            | Postprocessing                  |
|--------------------------|---------------------------------|
| • time gain compensation | • any change after freeze frame |
| • log compression        | • black/white inversion         |
| • write magnification    | • read magnification            |
| • persistence            | • contrast variation            |
| • spatial compounding    | • 3-D rendering                 |
| • edge enhancement       |                                 |
| • fill-in interpolation  |                                 |

## Magnification

With **magnification** (or *zoom*), the sonographer can improve visualization of anatomic detail by enlarging a portion of an image to fill the entire screen.

The selected part of the image is known as the *region of interest*, or ROI (see Fig. 15.8).

Two different forms of magnification exist:

1. read magnification
2. write magnification

### 1. Read Magnification

Read magnification occurs after the image data is stored in the scan converter. It consists of three steps (see Fig. 15.9):

1. The ultrasound system scans the anatomy.
2. The image is converted from analog to digital form and is stored in the scan converter.
3. The sonographer identifies the region of interest, and the system reads and displays **only the original data** that pertains to the region of interest. The ROI is not rescanned.

Read magnification is characterized by:

- The number of pixels or scan lines in the magnified image is the same as in the original image.

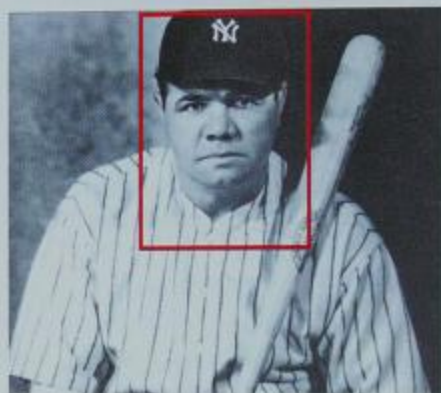


**Fig. 15.8** Image with region of interest (ROI) identified with the red box.



**Fig. 15.9** Read magnification of the ROI in Fig. 15.8 creates larger pixels from the information that is already in the scan converter.

- Spatial resolution does not change because the number of pixels in the ROI is unchanged. However, the pixels are larger in the zoomed image.

Read magnification can be used on a frozen image and is postprocessing.

## 2. Write Magnification

Write magnification is applied during data acquisition, before storage in the scan converter. It consists of four steps (see Fig. 15.10):

1. The ultrasound system scans the anatomy and creates an image.
2. The image is converted from analog to digital form and is stored in the scan converter.
3. The sonographer identifies the region of interest. At that moment, the system discards all the existing data in the scan converter.
4. The ultrasound system then **rescans only the region of interest** and writes new data into the scan converter.

Write magnification is characterized by:

- The image used to identify the ROI is discarded and all new image information is acquired.
- The number of pixels or scan lines in the ROI image is greater than that in the ROI's portion of the original image.



**Fig. 15.10** Write magnification rescans the region of interest in Fig. 15.8 and creates a new image with increased spatial resolution.



- The increased number of pixels in the region of interest improves spatial resolution. The pixels are the same size in both the old and the zoomed image.

Write magnification cannot be used on a frozen image and thus, is preprocessing.

**Hint:** With write magnification, temporal resolution may be improved if the bottom of the region of interest is shallower than the original image's depth of view (see page 200).

Table 15.7 Read and Write Magnification

| Read Magnification                        | Write Magnification                    |
|-------------------------------------------|----------------------------------------|
| • uses old data                           | • acquires new data                    |
| • postprocessing                          | • preprocessing                        |
| • larger pixel size                       | • identical pixel size                 |
| • same # of pixels as in the original ROI | • more pixels than in the original ROI |
| • unchanged spatial resolution            | • improved spatial resolution          |
| • unchanged temporal resolution           | • may improve temporal resolution      |

## Coded Excitation

Coded excitation is a sophisticated method of improving image quality.

Traditional ultrasound pulses are very short and the energy within the pulse is highest around its main frequency (see “Backing Material” on page 117).

Typically, short pulses provide superior axial resolution; however, the peak intensity is high.

In part, coded excitation was developed within the context of bioeffects. The Food and Drug Administration has established maximum peak intensity levels for sound beams. Intensities created by diagnostic transducers cannot exceed these limits, which impacts image quality.

Coded excitation creates very long sound pulses containing a wide range of frequencies (see Fig. 15.11). This specially designed long pulse distributes energy over a broad frequency range. The coded pulse is strong but still keeps the peak intensity below the FDA's limit. Improved penetration results.

Coded excitation occurs in the pulser.

With coded excitation, special mathematical techniques alter the long reflected pulses into a form suitable for high image quality. The coding of the excitation shortens the pulse with mathematical computation and improves resolution.

The following characteristics of coded excitation should be appreciated:

**Table 15.8 Advantages of Coded Excitation**

| Coded excitation provides...   |
|--------------------------------|
| • higher signal-to-noise ratio |
| • improved axial resolution    |
| • improved spatial resolution  |
| • improved contrast resolution |
| • deeper penetration           |

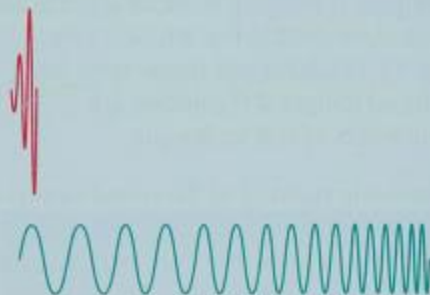


**Fig. 15.11** Short pulses are used in traditional imaging (red). Long complex pulses are used in coded excitation (green). Sophisticated computer programs create optimal images from coded reflections.

## Spatial Compounding

Spatial compounding is a method of using sonographic information from several different imaging angles to produce a single image. Compound imaging starts by acquiring multiple frames from different viewing angles as shown in Fig. 15.12. The frames are combined (overlapped or compounded) to form a single real-time image.

The number of frames and steering angles varies, depending on the transducer characteristics and the clinical application. In general, the more frames in the compound acquisition sequence, the better the compound image quality. Compound imaging reduces speckle and minimizes shadowing artifacts (see Fig. 15.13). Reduced frame rates and reduced temporal resolution are limitations of this technique.

Electronic steering of the sound beams is used in compound imaging. This technique is available only with phased array transducers.

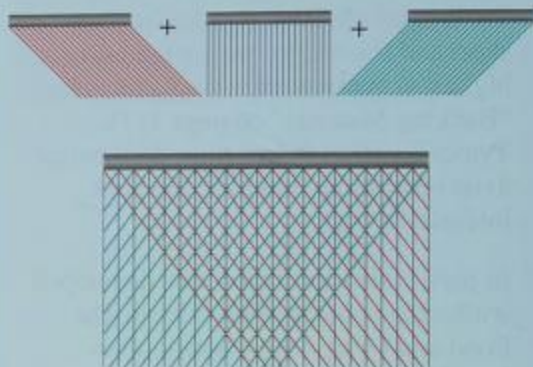


**Fig. 15.12** Spatial compounding averages multiple frames obtained by steering the sound beams in different directions. Multiple images are obtained from different imaging angles.

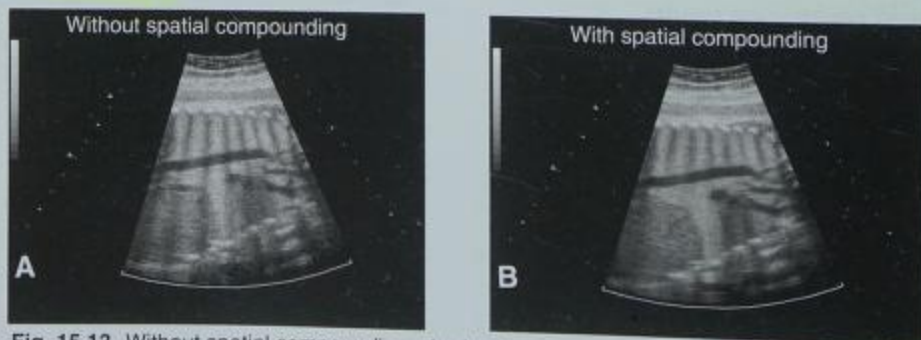


**Fig. 15.13** Without spatial compounding, shadowing appears in the image, image A. Spatial compounding reduces the shadowing artifact (image B).



## Frequency Compounding

Frequency compounding is an advanced technique that reduces speckle artifact and noise in ultrasound images. All reflected sound pulses contain a large range of frequencies. In traditional imaging, an image is created using the entire reflection with all of these frequencies, black spectrum (see Fig. 15.14). With frequency compounding, the reflected signal is divided into sub-bands of limited frequencies, and an image is created from each sub-band. The images from the sub-bands are then combined, or compounded, into a single image.

It is as if multiple images were created from transducers with different frequencies. The noise components of the reflections are different for each sub-band, and when combined, the noise level is reduced.

## Edge Enhancement

Edge enhancement is an image processing method that makes pictures look sharper (see Fig. 15.15). The computer identifies and emphasizes sharp edge boundaries in the image, such as the reflecting surface between two media with different gray scale levels.

This method works by increasing the image contrast in the area immediately around the edge. Edge enhancement creates subtle bright and dark highlights on either side of these boundaries to make them appear more defined.

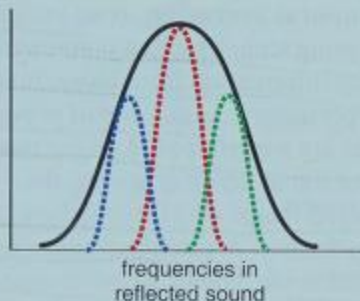


Fig. 15.14 With frequency compounding, the reflected sound wave (black) is divided into parts with different frequency ranges, called sub-bands (blue, red, and green).

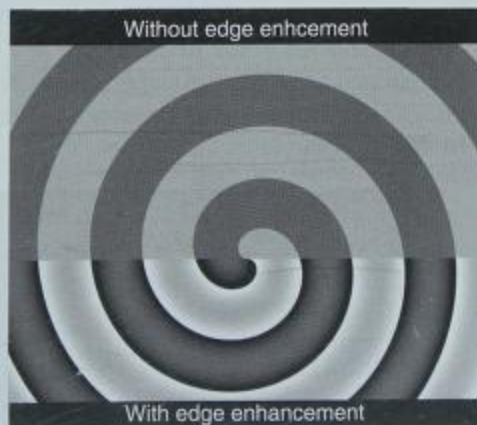


Fig. 15.15 Compare the top and bottom halves of this image. Edge enhancement has been used on the bottom, making the edges appear sharper.

## Temporal Compounding

**Temporal compounding, persistence, or temporal averaging**, is an image processing technique that continues to display information from older images. With persistence, a number of previous frames are superimposed on the most current frame. In other words, the displayed image contains "history" from earlier frames. A smoother image with reduced noise, higher signal-to-noise ratio, and improved image quality is produced (see Fig. 15.16).

The primary limitation of persistence is a reduction in the displayed frame rate, which reduces temporal resolution. Persistence is most effective with slowly moving structures (see Fig. 15.17). It is less useful when imaging rapidly moving structures, such as heart valves, because rapid motion cannot be observed accurately.

Persistence and spatial compounding differ in that all of the images used in persistence are from the same view. The images used in spatial compounding are from different views or angles.

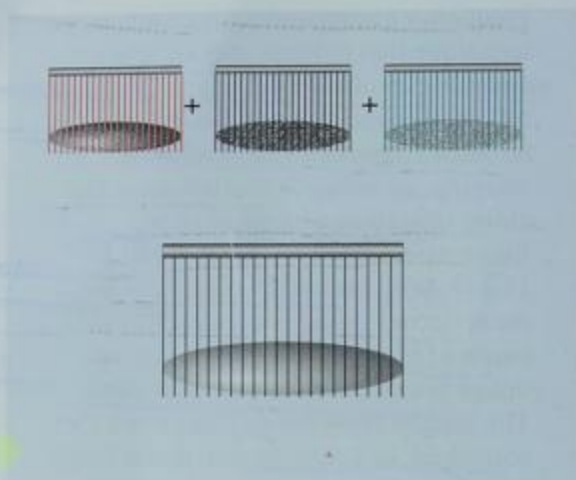


**Fig. 15.16** Persistence superimposes the current frame on previous frames to create a smoother image. The larger image above is a composite of the smaller red, black, and green frames. Notice the improved image created with persistence.

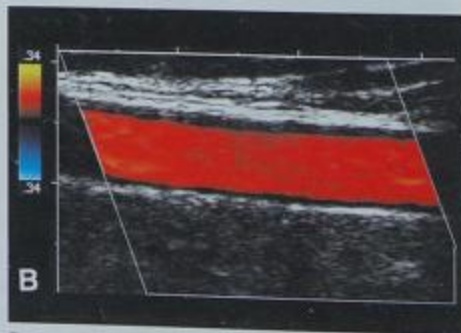
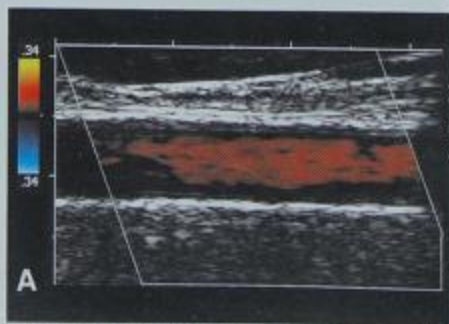


**Fig. 15.17** Without persistence (image A), color Doppler from a single frame does not fill the vessel. With persistence (image B), the entire lumen of the vessel is filled.



## Fill-in Interpolation

Two-dimensional ultrasound images are created from multiple ultrasound pulses directed into the body. With sector-shaped images, the scan lines separate at increasing depths. Gaps, or missing data, exist between the scan lines, especially as the lines spread apart (see Fig. 15.18, top). Interpolation is a method of constructing new simulated data points to fill in the gaps. The goal of fill-in interpolation is to fill in the gaps of missing data in a way that cannot be detected by the observer.

Sophisticated computer programs are able to predict the gray scale levels of missing data. The program uses the known gray scale levels of neighboring pixels to predict the missing information. Fill-in interpolation is a form of preprocessing. The line density increases, improving spatial resolution. For example, fill-in interpolation improves the ability to precisely visualize the borders of round structures.

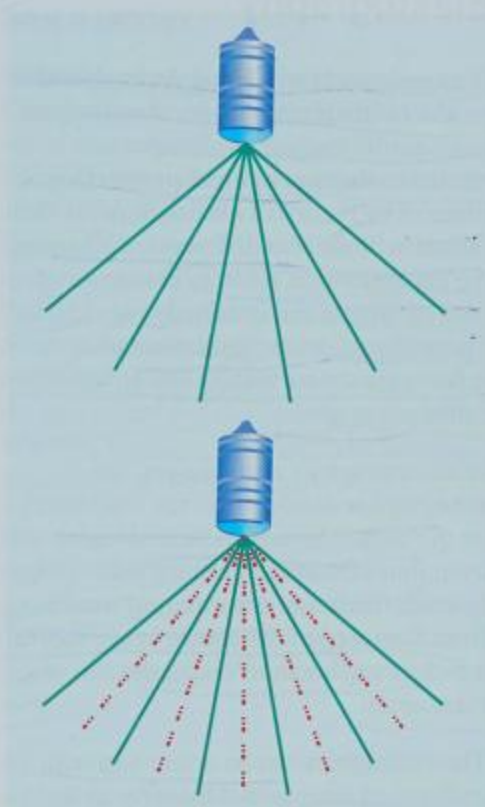


**Fig. 15.18** The upper image has a low line density. Gaps exist between the scan lines. Fill-in interpolation predicts what information lies between the gaps (red dashed lines) and improves spatial resolution.



## Emerging Technology: Elastography

Elastography is a dynamic technique that produces images from sound reflections in an entirely new way. Images are related to the **mechanical properties** of tissue. The theory of elastography is that tissues will deform differently following the application of a force. Estimates of tissue stiffness are obtained (Fig. 15.19). The stiffness data and ultrasound reflections are combined into images called elastograms.

In elastography's early stages, the sonographer would press the transducer on the tissues to distort them. Recent techniques no longer require this. Instead, the tissue deformation results from the force of the sound beam itself, which is sufficient to create the elastogram.

The elastogram can be combined with anatomical images and Doppler to add to the diagnostic value of the ultrasound exam. Elastography has been applied to differentiate malignant from benign lesions (see Fig. 15.20). Elastography has potential as a complementary tool for the diagnosis of cancer; however, scientific studies are needed to confirm and establish its diagnostic accuracy.

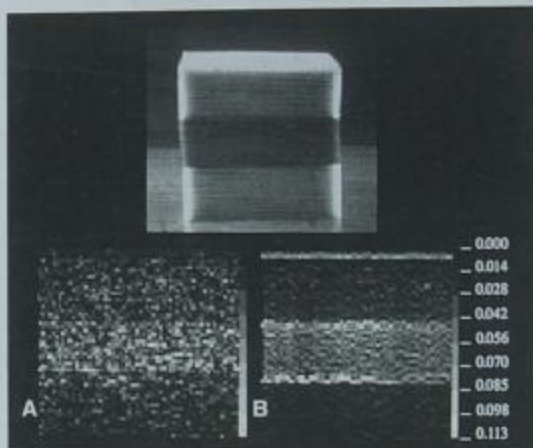


**Fig. 15.19** Sonogram (A) and elastogram (B) of sponge layers with different stiffness. The elastogram is based on differing stiffness and thus differentiates the layers more effectively.

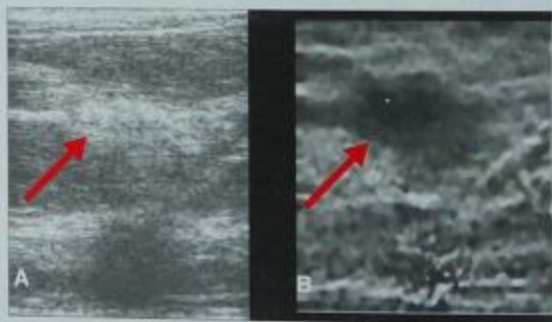


**Fig. 15.20** Sonogram (A) and elastogram (B) of a ductal carcinoma (arrow). The elastogram is based on differing stiffness and thus differentiates the carcinoma more effectively.  
Source: The images on this page are copyrighted by the University of Texas Medical School Houston and are provided by permission of Prof. Jonathan Ophir.

## PACS and DICOM

### *What is a PACS system?*

PACS, which stands for **Picture Archiving and Communications System**, describes the digital ultrasound laboratory in which images and additional medical information are digitized and stored on a large computer network.

PACS has three major advantages:

- virtually instant access to archived studies
- no degradation of data, which often happens over extended time periods with analog archiving
- “store and forward” telemedicine, the ability to electronically transmit images and reports to remote sites.

### *How are information and images stored in a PACS?*

The archival system is an important component of a PACS and is responsible for electronic storage of image data. Computer hard drives are the primary digital storage devices used in PACS.

The standard computer hard drive is a fast medium from which to retrieve data. Presently available devices have rapidly increasing capacity and decreasing cost.

### *What is DICOM?*

**DICOM** stands for **Digital Imaging and Computers in Medicine**. DICOM is a set of rules, or protocols, that allows imaging systems to share information on a network. When a particular ultrasound system adheres to DICOM standards, the system can successfully connect to a PACS medical information network. By purchasing only imaging systems that conform to the DICOM standard, all of the individual devices will work together to share, manage, and distribute images, regardless of the manufacturer.

Not only does DICOM assure that current imaging modalities can communicate, it guarantees that all devices developed in the future will easily attach to the PACS network as well.

An example of the use of similar standards is Internet connectivity. Virtually all manufacturers design their computers and software with specific standards that allow their computers to attach to the Internet effortlessly.

In summary, PACS is the physical computer network. DICOM is the set of rules that allows the components of the network to communicate.



## Recording and Archiving Techniques

Many different technologies are used to record and store ultrasound images and reports. Each form of data storage has strengths and weaknesses.

Table 15.9 Types of Data Storage

| Type of Medium                         | Examples                                                                                                                             | Advantages                                                                                                                                                                    | Disadvantages                                                                                                                                                                                   |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Paper Media</b>                     | <ul style="list-style-type: none"> <li>Charts from pen writers</li> </ul>                                                            | <ul style="list-style-type: none"> <li>Portability</li> <li>Does not require a device to read</li> </ul>                                                                      | <ul style="list-style-type: none"> <li>Bulky, hard to store</li> <li>Difficult to make copies</li> <li>Cannot display dynamic images</li> </ul>                                                 |
| <b>Magnetic Media</b>                  | <ul style="list-style-type: none"> <li>Computer discs</li> <li>Computer memory</li> <li>Magnetic tape</li> <li>Video tape</li> </ul> | <ul style="list-style-type: none"> <li>Able to store large amounts of information efficiently</li> <li>Can store and play dynamic images</li> <li>Can record color</li> </ul> | <ul style="list-style-type: none"> <li>Can be erased by strong magnetic fields</li> </ul>                                                                                                       |
| <b>Chemically Mediated Photographs</b> | <ul style="list-style-type: none"> <li>Photographs</li> <li>Flat films</li> <li>Multiformat camera film</li> </ul>                   | <ul style="list-style-type: none"> <li>High resolution</li> <li>Accepted in the medical community</li> <li>Can produce color images</li> </ul>                                | <ul style="list-style-type: none"> <li>Bulky, difficult to store and retrieve</li> <li>Requires chemical processing</li> <li>Artifacts can arise from dirt or chemical contamination</li> </ul> |
| <b>Optical Media</b>                   | <ul style="list-style-type: none"> <li>Laser discs</li> <li>Compact discs</li> </ul>                                                 | <ul style="list-style-type: none"> <li>Store huge amounts of data</li> <li>Inexpensive</li> <li>Not erased by exposure to magnetic fields</li> </ul>                          | <ul style="list-style-type: none"> <li>Requires a display system</li> <li>No standardized format for image display and storage</li> </ul>                                                       |

As an exercise, expand the lists provided for each type of data storage.



# Review: Displays and Image Processing

| Questions                                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Which electronic component is required for gray scale imaging?<br>A. VCR<br>B. non-interlaced display<br>C. computer memory<br>D. scan converter                                                                                         | 1. D. Scan converter technology is used to create gray scale displays.                                                                                                                                                      |
| 2. Which of the following scan converters will provide the best spatial resolution?<br>A. 256 x 256 pixels<br>B. 512 x 512 pixels<br>C. 128 x 128 pixels<br>D. 1000 x 1000 pixels                                                           | 2. D. The scan converter with the highest number of picture elements produces the best spatial resolution in an image. Choice D has 1 million picture elements (1,000 x 1,000) and therefore, has the highest image detail. |
| 3. Which of these statements regarding a bit of computer memory is false?<br>A. It is the smallest element of an image.<br>B. It is bistable.<br>C. Eight bits combine to make a byte.<br>D. It is a component of a digital scan converter. | 3. A. A bit is not a part of an image. A bit is the smallest element of computer memory.                                                                                                                                    |
| 4. How many gray shades can be represented by a group of $4 = 2 \cdot 2 = 8 \times 2 = 16$ bits?<br>• 4 bits? $2 \cdot 2$<br>• 2 bits? $2 \cdot 2$ (4)                                                                                      | 4. To determine the number of gray shades that a group of bits can represent, simply multiply 2 by itself as many times as there are bits.<br>• 4 bits represent 16 shades.<br>• 2 bits represent 4 shades.                 |
| 5. What is the number of shades that can be represented by 3 bits?<br>$2 \cdot 2 \cdot 2 = 8$                                                                                                                                               | 5. We have 3 bits, so take the number 2 and multiply it by itself 3 times!<br>$2 \times 2 \times 2 = 8$<br>Eight different gray shades are stored using 3 bits.                                                             |

| Questions                                                                                                                                                                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                                               |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>6. What is the number of shades that can be represented by 8 bits?</p> <p><i>Handwritten: 2 · 2 · 2 · 2 · 2 · 2 · 2 · 2 = 256</i></p>                                                                                                                                                                                                                                                           | <p>6. With 8 bits, the number 2 is multiplied by itself 8 times!</p> $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 256$ <p>Thus, 256 different gray shades can be stored using 8 bits.</p>                                                                                                                      |
| <p>7. What is the number of shades that can be represented by 10 bits?</p>                                                                                                                                                                                                                                                                                                                         | <p>7. With 10 bits, the number 2 is multiplied by itself 10 times!</p> $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 1024$ <p>Thus, 1024 different gray shades can be stored using 10 bits.</p>                                                                                               |
| <p>8. What is the number of shades that can be represented by n bits?</p>                                                                                                                                                                                                                                                                                                                          | <p>8. With n bits, the number 2 is multiplied by itself n times!</p> <p><math>2^n</math> different gray shades can be stored using n bits.</p>                                                                                                                                                                                        |
| <p>9. How many bits are needed to store:</p> <ul style="list-style-type: none"> <li>• 10 shades of gray?</li> <li>• 11 shades of gray?</li> <li>• 15 shades of gray?</li> </ul>                                                                                                                                                                                                                    | <p>9. Four bits are required to store from 9 to 16 shades of gray.</p> <p>Three bits can store up to 8 shades of gray. Since a bit is the smallest amount of computer memory, a total of 4 bits are needed to store more than 8 different shades of gray. Four bits will actually store a maximum of 16 different shades of gray.</p> |
| <p>10. Which of the following statements regarding a pixel is false?</p> <ul style="list-style-type: none"> <li>A. It is the smallest part of a digital image.</li> <li>B. A collection of bits, assigned to each pixel, stores the shade of gray.</li> <li>C. It displays up to 3 gray shades simultaneously.</li> <li>D. Image quality is improved when the number of pixels is high.</li> </ul> | <p>10. C. At any given moment, a pixel can display only a single shade of gray. Think of a pixel as a square on a checkerboard. The coloration is uniform throughout.</p>                                                                                                                                                             |

| Questions                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>11. Are the following procedures usually pre- or postprocessing?</p> <p>A. modifying a frozen image<br/>B. read zoom<br/>C. write zoom<br/>D. adjusting the brightness on the monitor<br/>E. increasing the receiver gain</p>                                                                                                                 | <p>11.</p> <p>A. postprocessing<br/>B. postprocessing<br/>C. preprocessing<br/>D. postprocessing<br/>E. preprocessing</p>                                                                                                                        |
| <p>12. What is the primary disadvantage of video tape and computer disc methods of image archiving?</p> <p>A. these methods are very costly<br/>B. the information is vulnerable to erasure when exposed to strong magnetic fields<br/>C. only low resolution images are stored<br/>D. only black and white images are stored</p>                | <p>12. B. Data stored on videotape and computer discs can be erased by strong magnetic fields.</p>                                                                                                                                               |
| <p>13. Where does coded excitation take place?</p> <p>A. in the transducer<br/>B. in the receiver<br/>C. in the pulser<br/>D. in the PACS system</p>                                                                                                                                                                                             | <p>13. C. Coded excitation takes place in the pulser. Coded excitation is a sophisticated process of creating complex pulses to improve image quality.</p>                                                                                       |
| <p>14. Which of the following is not true about spatial compounding?</p> <p>A. data is collected from different viewing angles<br/>B. frame rates are reduced<br/>C. shadowing artifact can be eliminated<br/>D. can be performed with a mechanical transducer</p>                                                                               | <p>14. D. Spatial compounding is performed only with phased array transducers that electronically steer sound beams in different directions. Mechanical transducers cannot perform spatial compounding.</p> <p>Choices A, B, and C are true.</p> |
| <p>15. All of the following are advantages of PACS systems except:</p> <p>A. data will not deteriorate over time<br/>B. images can be delivered to distant locations on the imaging network<br/>C. older, archived studies and reports can be reviewed easily<br/>D. images have higher resolution than what appears on the system's display</p> | <p>15. D. Image resolution is not improved simply with the use of a PACS system.</p>                                                                                                                                                             |



| Questions                                                                                                                                                                                                                                                                    | Answers                                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>16. What is DICOM?</p> <ul style="list-style-type: none"> <li>A. standards for transducer design</li> <li>B. standards for patient exposure</li> <li>C. protocols for two-dimensional imaging</li> <li>D. protocols for medical image data</li> </ul>                     | <p>16. D. DICOM is a set of standards that allow medical imaging systems to communicate over a network.</p>                                                                                                                |
| <p>17. What is the primary storage device on a PACS system?</p> <ul style="list-style-type: none"> <li>A. magneto-optical storage</li> <li>B. hard disc drives</li> <li>C. solid state memory</li> <li>D. compact discs</li> </ul>                                           | <p>17. B. hard disc drives. PACS uses a collection of disc drives, or network storage devices, to store data.</p>                                                                                                          |
| <p>18. Which of the following technologies uses long sound pulses to create an image?</p> <ul style="list-style-type: none"> <li>A. coded excitation</li> <li>B. harmonics</li> <li>C. pulse inversion</li> <li>D. rendering</li> </ul>                                      | <p>18. A. coded excitation. Very long pulses are created with coded excitation. Advanced mathematical techniques are used to shorten the pulse to create an optimal image. Coded excitation takes place in the pulser.</p> |
| <p>19. With frequency compounding, how many pulses are transmitted down each scan line?</p> <ul style="list-style-type: none"> <li>A. 1</li> <li>B. 2</li> <li>C. 4</li> <li>D. cannot be determined</li> </ul>                                                              | <p>19. A. 1. With frequency compounding, one pulse is transmitted down each scan line. The data from the reflection of that one pulse is divided into sub-bands.</p>                                                       |
| <p>20. Which of the following techniques is used to create image data where none really exists?</p> <ul style="list-style-type: none"> <li>A. edge enhancement</li> <li>B. temporal compounding</li> <li>C. fill-in interpolation</li> <li>D. spatial compounding</li> </ul> | <p>20. C. fill-in interpolation. Fill-in interpolation is used when gaps exist between scan lines. The information created by this technique is a prediction based on the actual data that surrounds the gaps.</p>         |
| <p>21. In modern elastography, how are the tissues deformed?</p> <ul style="list-style-type: none"> <li>A. by pressing the transducer into the skin</li> <li>B. with the use of a second probe</li> <li>C. automatically</li> <li>D. as a result of respiration</li> </ul>   | <p>21. C. automatically. Current elastographic techniques collect information from tissues that are deformed by the sound beam itself. No additional steps are required to deform the tissues.</p>                         |

## Dynamic Range

Most devices can accurately process signals only within a particular range. **Dynamic range** is a method of describing the extent to which a signal can vary and still maintain accuracy. In effect, we can think of dynamic range as “number of available choices.”

For example, consider a typical bathroom scale that accurately weighs objects between 30 and 300 pounds.

- Signals (weights) below 30 pounds are too weak. The needle on the scale does not move and the information is disregarded as noise. Weak signals are below the system's **threshold**.
- Signals (weights) above 300 pounds are too strong. All signals above 300 pounds are displayed as *equal to 300* pounds. These strong signals **saturate** the system.
- Thus, a scale's range of **accurate** measurement is 30 to 300 pounds—excellent for measuring the weight of an adult, but not suitable for measuring the weight of a bunch of grapes or an automobile.

### Dynamic Range

A method of reporting the extent to which a signal can vary and still be accurately measured.

#### Units

Dynamic range is reported in units of **decibels (dB)**. It is a **comparison**, a **relative measurement**, or a **ratio**, between the largest and smallest signals that are measured accurately.

Returning to the bathroom scale analogy, we could report the ratio as  $300 \div 30$ , or 10:1—the largest signal is 10 times greater than the smallest.

The term “10:1” is not in the appropriate form. **Dynamic range has units of decibels.**

## Dynamic Range of System Components

The individual components of a system have different dynamic ranges.

As a general rule, **the dynamic range of information decreases the more it is processed**. Therefore, the components earliest in the imaging chain (such as the transducer) process data with the widest dynamic range. Components farther along in the imaging chain (such as the display or storage) process data with narrower dynamic ranges.

Table 16.1 Dynamic Range of Components

| Component      | Dynamic Range |
|----------------|---------------|
| transducer     | 120 dB        |
| receiver       | 100 to 120 dB |
| scan converter | 40 to 50 dB   |
| display        | 20 to 30 dB   |
| archive        | 10 to 30 dB   |

## Compression of Dynamic Range

Problems may arise when the dynamic range of one component of an ultrasound system is narrower than that of another component. For example, the dynamic range of the system's receiver may be 100 dB, while the scan converter's dynamic range is only 60 dB. If nothing is done, inaccuracies may result when signals pass from the receiver to the scan converter. The process of compression eliminates these potential errors.

Furthermore, the dynamic range of the human eye is narrower than that of the system's display. The image information must be compressed for us to effectively see the meaningful clinical information.

**Compression is a technique that reduces the dynamic range of a signal without introducing errors.** The requirements of compression are as follows:

- the largest signal remains the largest
- the smallest signal remains the smallest
- the range of signals is reduced

The grading system at college illustrates the compression process. During the semester, students receive grades ranging from 100 to 0. However, at the end of the semester, the professor compresses the grades into a range of 4 to 0 (A=4, B=3, C=2, D=1, and F=0).

The range of scores is reduced; however, the ranking of each student from highest to lowest remains unchanged. The student with the highest numerical average earns an "A." The student with the lowest average earns an "F."

The sonographer can adjust compression.



## Mathematics of Compression

The mathematics of compression using decibels are straightforward: decibels *add* or *subtract*. The following questions illustrate the concept.

| Questions                                                                                                                                                                                              | Answers                                                                                             |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| 1. An uncompressed signal within the receiver of an ultrasound system has a dynamic range of 110 dB. The signal undergoes 40 dB of compression. What is the dynamic range of the compressed signal?    | 1. The dynamic range of the compressed signal is<br>$110\text{ dB} - 40\text{ dB} = 70\text{ dB}$ . |
| 2. An uncompressed signal has a dynamic range of 85 dB. The signal undergoes 30 dB of compression. What is the dynamic range of the compressed signal?                                                 | 2. The dynamic range of the compressed signal is<br>$85\text{ dB} - 30\text{ dB} = 55\text{ dB}$ .  |
| 3. After compression, a signal within the ultrasound system has a dynamic range of 70 dB. The original signal was compressed by 40 dB. What is the dynamic range of the original, uncompressed signal? | 3. The dynamic range of the original signal is<br>$70\text{ dB} + 40\text{ dB} = 110\text{ dB}$ .   |
| 4. A signal within a system's receiver has a dynamic range of 60 dB after compression. The original signal was compressed by 50 dB. What is the dynamic range of the original, uncompressed signal?    | 4. The dynamic range of the original signal is<br>$60\text{ dB} + 50\text{ dB} = 110\text{ dB}$ .   |

## Number of Choices

An alternative description of dynamic range is **number of choices**. The dynamic range of a display can be reported as the number of possible gray shades.

- **Narrow dynamic range** means fewer gray shades, as shown in Fig. 16.1A. A **bistable image**; that is, one that contains only black and white, has the narrowest dynamic range. Images that display few shades of gray are also called **high contrast**.
- **Wide dynamic range** means many shades of gray, as shown in image Fig. 16.1B. A **gray scale image**; that is, one that contains many shades of gray has the widest dynamic range. Images that display many shades of gray are also called **low contrast**.



**Fig. 16.1** Image A has a narrow dynamic range since it has few gray shades. Image B has a wide dynamic range since it displays many shades of gray.

**Table 16.2** Images and Their Dynamic Ranges

| Fewer Shades—Fig. 16.1A      | More Shades—Fig. 16.1B |
|------------------------------|------------------------|
| • few choices                | • many choices         |
| • black and white (bistable) | • gray scale           |
| • narrow dynamic range       | • wide dynamic range   |
| • high contrast              | • low contrast         |

# Harmonics and Contrast Agents

Harmonic imaging and contrast agents are two significant advancements in diagnostic ultrasound. These new technologies can salvage suboptimal studies and increase the diagnostic accuracy of ultrasonic imaging and Doppler.

## What is Harmonic Imaging?

Harmonic imaging is the creation of an image from sound reflections at twice the frequency of the transmitted sound.

For example, a transducer transmits a sound pulse with a frequency of 2 MHz. The transmitted frequency is called the **fundamental** frequency. In harmonic mode, the image is created from sound reflections with a frequency of 4 MHz. The **harmonic** frequency is twice the transmitted frequency.

Harmonic frequency sound waves arise from **nonlinear behavior**.

### Fundamental frequency

The frequency of sound created by the transducer and transmitted into the body.

### Harmonic frequency

Twice the fundamental frequency (also called **second harmonic frequency**).



## Fundamental and Harmonic Images

### Fundamental image

The image created by processing reflections that have the same frequency as the transmitted sound.

### Harmonic image

The image created by processing reflections that are twice the fundamental frequency.

A small but significant percentage of clinical studies are suboptimal because of sound beam distortion. Harmonic imaging is most useful in improving poor quality images because harmonic frequency waves undergo less distortion than fundamental sound waves.

Two forms of harmonics are important in diagnostic sonography:

- tissue harmonics and
- contrast harmonics.

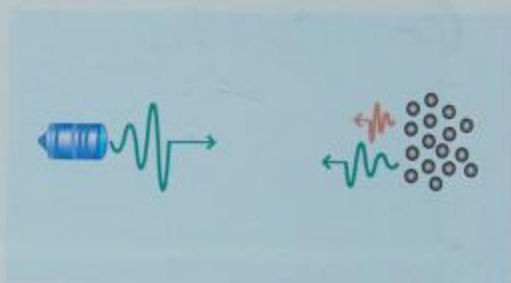


**Fig. 17.1** Fundamental imaging creates images from sound reflections with the same frequency as the transducer frequency (green reflection).



**Fig. 17.2** Harmonic imaging creates images from sound reflections that are twice the transducer frequency (red reflection).

## Linear and Nonlinear Behavior

### Linear behavior

**Linear** means **proportional** or **symmetrical**. Linear systems respond in an even manner.

For example, an elevator at the ground floor of a hospital takes 10 seconds to travel from the ground floor to the first floor, 20 sec to reach the second floor, 30 sec to reach the third floor, and so on. Movement between any adjacent floors requires 10 seconds.

This behavior is linear because it is even, or proportional. **Linear behavior is symmetrical** (see Fig. 17.3).

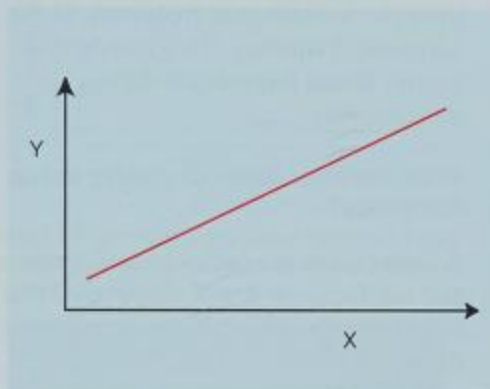


Fig. 17.3 Graphical representation of linear behavior.

### Nonlinear behavior

**Nonlinear** means **irregular** or **disproportionate**. A system is nonlinear when it behaves unevenly.

For example, a different elevator at the ground floor of a hospital takes 10 sec to travel from the ground floor to the first floor, 16 sec to reach the second floor and 19 sec to reach the third floor.

This behavior is nonlinear because it is uneven or disproportional. **Nonlinear behavior is asymmetrical** (see Fig. 17.4).

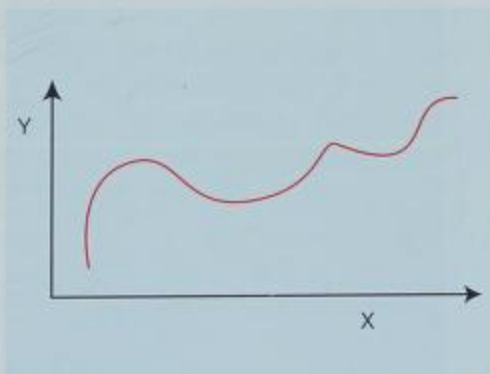


Fig. 17.4 Graphical representation of nonlinear behavior.

**Note:** Harmonic frequency sound arises from nonlinear behavior.

## Tissue Harmonics

As a sound wave travels in the body, a miniscule amount of energy is converted from the fundamental frequency to the harmonic frequency. This conversion creates **tissue harmonics** during transmission.

### *What nonlinear behavior creates tissue harmonics?*

A sound wave is a series of compressions and rarefactions. It was discovered that sound travels at slightly uneven speeds through soft tissue—faster through compressions and slower through rarefactions. This nonlinear variation in speed creates tissue harmonics in the biologic media (see Fig. 17.5).

The variation in speed alters the shape of the sound beam, and a very small amount of energy is transferred from the fundamental frequency to the harmonic frequency. In essence, the strength of the harmonic wave grows as sound travels in tissue.

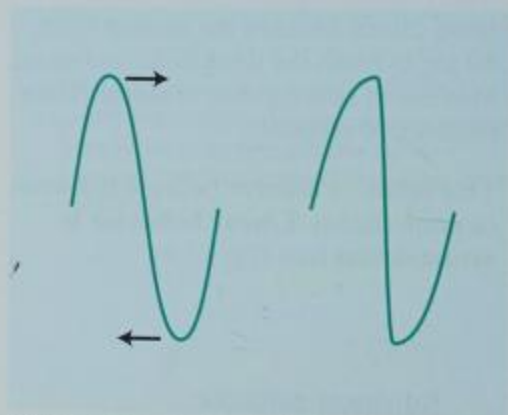


**Fig. 17.5** The nonlinear behavior of sound propagation as it travels through tissue produces harmonics. The cycles distort because sound crests travel faster than sound troughs.



### ***What is the significance of the gradual development of a harmonic signal?***

During fundamental imaging, significant amounts of artifact arise within the first few centimeters of tissue. These strong artifacts appear for two reasons:

- the beam is very strong
- the many different superficial anatomic layers distort the sound beam

Tissue harmonic signals do not exist at extremely superficial depths; they develop deeper in the tissue. Because they do not exist in the superficial depths, harmonic signals cannot distort. In essence, harmonics get a “free ride” through the superficial tissues, thereby remaining distortion free with less noise (see Fig. 17.6). The use of harmonics increases the signal-to-noise ratio (see Fig. 17.7).

### ***Is there another form of nonlinear behavior that further minimizes distortion with tissue harmonics?***

With tissue harmonics, the relationship between sound beam strength and harmonic creation is also nonlinear.

If the relationship was linear, then weak beams would create weak tissue harmonics, medium strength beams would create medium harmonics, and strong beams would create strong harmonics. This is not the case.

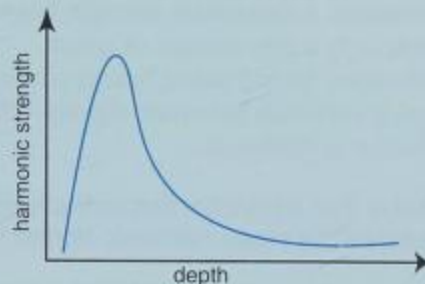


**Fig. 17.6** Strength of the tissue harmonic signal builds up as the wave travels deeper into the tissues and then dies down.

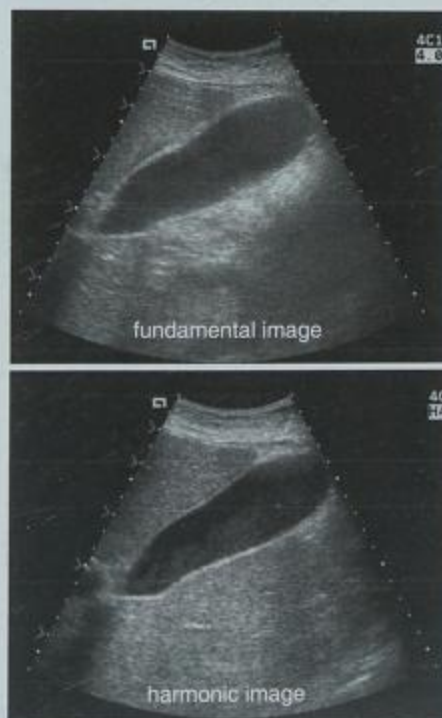


**Fig. 17.7** Distortion that degrades the fundamental image (upper) does not appear in the harmonic image (lower).

Weak sound beams do not create tissue harmonics; intermediate strength beams create only a tiny amount of tissue harmonics. Strong sound beams create significant tissue harmonic signals—this behavior is nonlinear.

***What is it so significant that only strong sound beams create harmonic signals?***

When sound beams are distorted, a small portion of the sound energy is directed away from the beam's main axis in the form of side lobes or grating lobes. However, most of the energy continues to propagate along the main beam (see Fig. 17.8).

Since the main beam is strong, harmonics are produced along the main beam. Since harmonics arise only in the non-distorted main beam, the harmonic image has less distortion. Very few harmonics are created in the lobes because they are so weak. **Beams that are most likely to create harmonics are least likely to create artifacts.**

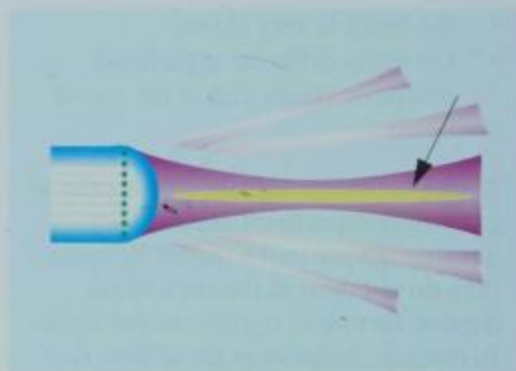


**Fig. 17.8** Harmonics, identified by the arrow, are produced only in the sound beam's main axis, where the beam is strong. They are not created in the weaker side lobes.

## Summary of Tissue Harmonics

Tissue harmonics are:

- not present as sound leaves the transducer; they are created deeper in the tissues.
- created in the tissues during **transmission**.

- created by **nonlinear behavior** in the speed of sound. Sound in compressions travels faster than sound in rarefactions.
- primarily created along the beam's main axis.

The beam contains no harmonic frequency sound at the skin's surface, thereby avoiding distortion and reducing noise.

## Pulse Inversion Harmonics

Pulse inversion harmonics is an imaging technique specifically designed to utilize harmonic reflections, which are distortion free, while eliminating distorted fundamental reflections.

Reflections contain both fundamental and harmonic frequencies. Fundamental imaging creates images from the portion of the reflected sound that has the same frequency as the transmitted sound. Harmonic imaging creates images only from the harmonic, which is twice the frequency of the transmitted sound.

Originally, filters were used to separate the harmonic signal from the fundamental, but filtering was only moderately effective. Modern techniques, such as pulse inversion harmonics, separate the harmonics from the fundamental frequencies more successfully.

With pulse inversion harmonics, two consecutive ultrasound pulses are transmitted down each scan line (see Fig. 17.9). The first is a typical pulse. The second pulse is an inverted copy that is out-of-phase with the first. Wherever a compression exists in the first pulse, a rarefaction exists in the second.

The reflections from these pulses are combined in the receiver. Since fundamental portions of the reflections exhibit linear behavior, the two inverse



**Fig. 17.9** With pulse inversion, a positive and then a negative pulse is transmitted down each scan line.



fundamental signals destructively interfere and completely cancel each other out. However, since harmonics exhibit nonlinear behavior, the harmonic portions of the reflections are in-phase and interfere constructively. Therefore, only the harmonic portions of the reflections remain while the fundamental portions disappear (see Fig. 17.10). The remaining harmonic reflections form an image with less distortion.

The disadvantage of pulse inversion harmonics is that two pulses are transmitted down each scan line and twice the number of pulses are required to create each image. The time required to create a frame is doubled, the frame rate is halved, and temporal resolution is reduced.

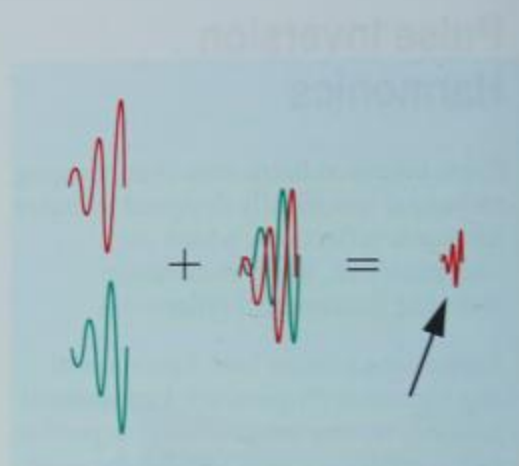


**Fig. 17.10** With pulse inversion harmonics, the positive and negative reflections are combined. The fundamental portions are eliminated, leaving only the harmonic part of the reflection (arrow).

### What is power modulation harmonic imaging?

Power modulation harmonics is another imaging technique specifically designed to augment harmonic reflections, which contain less distortion, while eliminating distorted fundamental reflections. It achieves the same goals as pulse inversion but uses a different engineering approach.

Two consecutive ultrasound pulses are sent down each scan line; the second pulse is twice the strength of the first one (see Fig. 17.11). Since harmonics exhibit nonlinear behavior, the weaker first reflection does not contain harmonics. The stronger second reflection contains harmonics.

During reception, the reflections from the first pulse are doubled and then subtracted from the second reflection. The fundamental portions of the two reflections completely cancel each other out, leaving only the harmonic portion of the second reflection. Then, the remaining harmonics form an image with less distortion than the fundamental image. Since two pulses are transmitted down each scan line, the frame rate is halved, and temporal resolution is reduced.

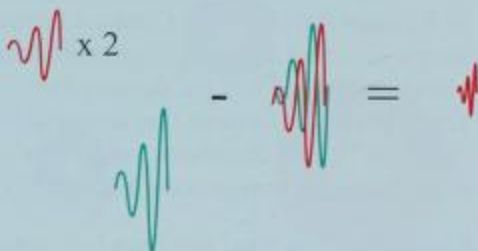


**Fig. 17.11** With power modulation, the harmonics are extracted by sending one strong pulse and one weak pulse down each scan line.

## Contrast Agents

Contrast agents, also called **microbubbles**, are gas bubbles encapsulated in a shell. They are injected in the circulation (usually intravenously) or ingested (swallowed). Contrast agents have a different acoustic fingerprint than blood or tissue. They are designed to create strong reflections that actually “light up” blood chambers, vessels, or other anatomic regions (see Fig. 17.12).

Contrast agents must meet the following five requirements:

- safe
- metabolically inert
- long lasting
- strong reflector of ultrasound
- small enough to pass through capillaries

## Contrast Harmonics

We know that tissue harmonics are created as sound travels in tissues. As an ultrasound pulse interacts with contrast agents, much stronger harmonics are generated. Contrast harmonics are created because microbubbles act in a nonlinear manner when struck by sound waves (see Fig. 17.13). Contrast harmonics are created **during reflection** as energy is converted from the fundamental frequency to the harmonic frequency.



**Fig. 17.12** Cardiac ultrasound study using a contrast agent. The cardiac chamber is filled with contrast and is well defined. A blood clot (red arrow), surrounded by the contrast agent, appears as a round, black structure in the chamber.



**Fig. 17.13** Harmonics, represented by the red pulse, are created with reflection off of contrast microbubbles. The fundamental frequencies are in green.



### ***What nonlinear behavior of a microbubble creates contrast harmonics?***

A sound wave is an oscillation of pressure or a series of compressions and rarefactions. When a microbubble is within a sound beam, the bubble grows and shrinks in relation to these pressure variations. When exposed to sound beams of adequate strength, contrast harmonics are created because of the nonlinear changes in bubble size. This uneven behavior is called **resonance** (see Fig. 17.14).

When exposed to the high pressure component of a sound wave (compression), the bubble shrinks and the pressure inside the bubble increases. The bubble stabilizes, resisting further compression, which limits how small the bubble will become.

When exposed to the low pressure component of a sound beam (rarefaction), the bubble expands.

**Bubbles expand to a greater extent than they shrink.** With this uneven, or nonlinear, change in size, a small amount of energy is transferred from the fundamental frequency to the harmonic frequency. Therefore, peak rarefaction pressure, which expands the bubble, is most important with regard to contrast harmonics.

### ***What is the mechanical index?***

The amount of contrast harmonics produced may be estimated by a number called the **mechanical index** (MI). The mechanical index depends on the

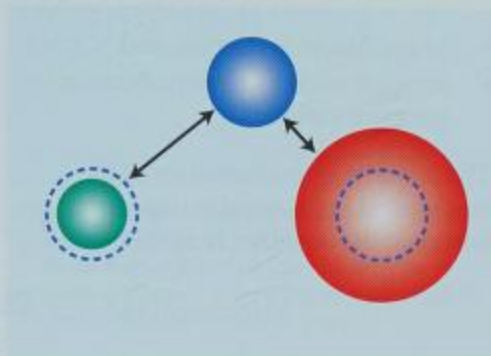


**Fig. 17.14** Nonlinear behavior of microbubbles. Contrast bubbles expand (red) to a greater extent than they compress (green).

frequency of the transmitted sound and the rarefaction pressure of the sound wave. The numerical value of the mechanical index, and therefore, harmonic production, increases with

- lower frequency sound, and
- stronger sound waves (substantial pressure variation).

The underlying mathematics of the mechanical index are not important; however, the equation is as follows:

$$\text{Mechanical Index} = \frac{\text{peak rarefaction pressure}}{\sqrt{\text{frequency}}}$$

### ***Why are microbubbles strong scatterers of sound waves?***

Under certain circumstances, a vibrating structure can produce large oscillations, or resonance, from a small driving force. For example, a child on a swing can reach great heights by kicking his heels at the appropriate time.

It is a fortunate coincidence that microbubbles the size of red blood cells resonate when exposed to sound in the 2 to 4 MHz range. This range is right in the middle of the frequencies used in diagnostic ultrasonography.

### ***Is there another form of nonlinear behavior of a microbubble that creates contrast harmonics?***

Yes. A second form of nonlinear behavior occurs with contrast agents. The relationship between the mechanical index and harmonic creation is nonlinear.

Table 17.1 Comparison of High and Low Mechanical Indices

| Lower MI                   | Higher MI                  |
|----------------------------|----------------------------|
| • small pressure variation | • large pressure variation |
| • higher frequency         | • lower frequency          |

If the relationship was linear, then a low mechanical index sound beam would create weak harmonics, intermediate mechanical index beams would create medium harmonics, and high MI beams would create strong harmonics. This is not the case. See Fig. 17.15.

**Low mechanical index** sound beams do not create harmonics because the microbubbles expand and contract evenly in a **linear** fashion. When the mechanical index is less than 0.1, bubbles create only backscatter—similar to other biologic reflectors.

Beams with an intermediate mechanical index, 0.1 to 1.0, create a relatively small amount of harmonics.

Beams with a high mechanical index (greater than 1.0) create substantial harmonic signals. With high mechanical index sound beams, the bubbles may expand and break apart. Bubble disruption is an example of extreme nonlinear behavior, which creates very strong harmonic reflections.

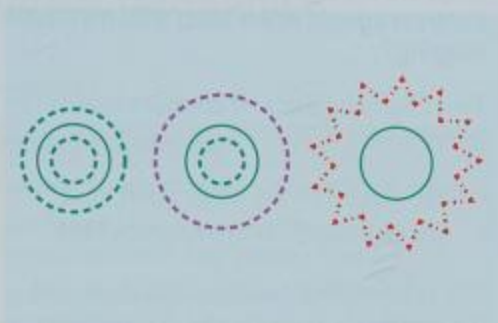


**Fig. 17.15** Mechanical index determines the behavior of microbubbles. Low MI creates linear behavior (left), higher MI creates nonlinear behavior (middle), and very high MI creates bubble disruption (right).

**Table 17.2 Mechanical Index and Harmonics**

| Low MI: less than 0.1        | Higher MI: 0.1 to 1.0       | Highest MI: greater than 1   |
|------------------------------|-----------------------------|------------------------------|
| • no harmonics               | • some harmonics            | • strongest harmonics        |
| • backscatter                | • resonance                 | • bubble disruption          |
| • linear behavior            | • nonlinear behavior        | • extreme nonlinear behavior |
| • higher frequency sound     | • lower frequency sound     | • lowest frequency sound     |
| • low beam strength          | • higher beam strength      | • highest beam strength      |
| • bubble expands very little | • bubble expands moderately | • bubble expands greatly     |



**What are the important characteristics of contrast agents when used with harmonic imaging?**

Two characteristics of contrast agents are important:

- the nature of the outer shell, and
- the gas that fills the microbubble

The relationship between the shell and the internally trapped gas determines the contrast agent's stability and its longevity while circulating in blood.

- Shells trap the gas and increase the effective life of a microbubble. Gas bubbles without shells, such as those found in agitated saline, shrink and quickly vanish as the gas dissolves in blood.
- Shells are designed to be flexible so that they can change shape. Rigid shells tend to fracture, resulting in bubble disruption.
- The gas trapped in the interior of the shell also determines the stability of the microbubble. Smaller gas molecules are more likely to leak through the shell and shrink the bubble. Larger gas molecules find the shell less permeable and remain trapped within the bubble.

System manufacturers and developers of contrast agents collaborate to optimize the performance of these agents. Understanding the interaction between sound beams and microbubbles enhances their clinical utility.

**How do the strengths of tissue and contrast harmonics compare?**

Contrast harmonics created by microbubbles are much stronger than tissue harmonics.

## Summary of Contrast Harmonics

Contrast harmonics are:

- created during **reflection**.
- created by **nonlinear behavior** of the microbubble. Resonance creates some harmonics. Bubble disruption creates very strong harmonics.
- related to the **mechanical index**. A low mechanical index is associated with no harmonics. Intermediate levels of MI are associated with weaker harmonics as a result of resonance. High MIs are associated with bubble disruption, which causes a great deal of harmonics.
- affected by the microbubble's shell and the gas within it.

# Summary of Tissue and Contrast Harmonics

Table 17.3 Comparison of Tissue and Contrast Harmonics

| Tissue Harmonics                                                                                              | Contrast Harmonics                                                                                                             |
|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• created during transmission in tissue</li> </ul>                     | <ul style="list-style-type: none"> <li>• created during reflection off of microbubble</li> </ul>                               |
| <ul style="list-style-type: none"> <li>• occurs as sound propagates in tissue</li> </ul>                      | <ul style="list-style-type: none"> <li>• occurs only when contrast agents are present and with MIs greater than 0.1</li> </ul> |
| <ul style="list-style-type: none"> <li>• results from nonlinear behavior of transmitted sound beam</li> </ul> | <ul style="list-style-type: none"> <li>• results from nonlinear behavior of microbubble</li> </ul>                             |
| <ul style="list-style-type: none"> <li>• weaker harmonic signal</li> </ul>                                    | <ul style="list-style-type: none"> <li>• stronger harmonic signal</li> </ul>                                                   |

| Questions                                                                                                                                                                                                    | Answers                                                                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| <p>1. Sound with a frequency of 4 MHz is created by a transducer. What is the fundamental frequency?</p> <p>A. 4 MHz<br/>B. 8 Mhz<br/>C. 2 Mhz<br/>D. cannot be determined with the information provided</p> | <p>1. A, 4 MHz. The fundamental frequency is that which is produced by the transducer.</p> |
| <p>2. Sound with a frequency of 4 MHz is created by a transducer. What is the harmonic frequency?</p> <p>A. 4 MHz<br/>B. 8 Mhz<br/>C. 2 Mhz<br/>D. cannot be determined with the information provided</p>    | <p>2. B, 8 MHz. The harmonic frequency is a multiple of the fundamental frequency.</p>     |
| <p>3. Which of the following creates harmonics?</p> <p>A. reflection<br/>B. transmission<br/>C. linear behavior<br/>D. nonlinear behavior</p>                                                                | <p>3. D, nonlinear behavior. Nonlinear behavior creates harmonics.</p>                     |

| Questions                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                           |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4. Where are harmonics created?<br>A. in the pulser<br>B. in the transducer<br>C. in the tissues<br>D. in the receiver                                                                                                                                                                                                          | 4. C, in the tissues. Harmonics are created in the tissues.                                                                                                       |
| 5. What nonlinear behavior creates tissue harmonics?<br>A. microbubbles expand to a greater extent than they compress<br>B. sound reflects off of boundaries with different impedances<br>C. sound travels faster in compressions and slower in rarefactions<br>D. microbubbles compress to a greater extent than they expand   | 5. C. Tissue harmonics are created by nonlinear behavior; sound travels faster in compressions and slower in rarefactions.                                        |
| 6. What nonlinear behavior creates contrast harmonics?<br>A. microbubbles expand to a greater extent than they compress<br>B. sound reflects off of boundaries with different impedances<br>C. sound travels faster in compressions and slower in rarefactions<br>D. microbubbles compress to a greater extent than they expand | 6. A. Contrast harmonics are created by nonlinear behavior; microbubbles expand to a greater extent than they compress.                                           |
| 7. Which of the following is associated with the highest mechanical index?<br>A. low frequency, extreme peak rarefactional pressure<br>B. high frequency, extreme peak rarefactional pressure<br>C. low frequency, extreme peak compression pressure<br>D. high frequency, extreme peak compression pressure                    | 7. A, low frequency, extreme peak rarefactional pressure. Mechanical index is directly related to peak rarefactional pressure and inversely related to frequency. |



# Hemodynamics

**Hemodynamics** is the study of blood moving through the circulatory system.

## Flow

**Flow**, also called **volume flow rate**, indicates the volume of blood moving during a particular time. Flow measurements answer the question: “how much?”

## Units

The units of flow are volume divided by time, such as liters/min; for example, 5 L/min.

## Velocity

**Velocity** indicates the speed or swiftness of a fluid moving from one location to another. Velocity answers the question: “how fast?”

## Units

The units of velocity are distance divided by time, such as cm/s; for example, 200 cm/s.

## Flow

Three basic forms of blood flow are:

- pulsatile
- phasic
- steady

### Pulsatile Flow

**Pulsatile flow** occurs when blood moves with a variable velocity. Blood accelerates and decelerates as a result of **cardiac contraction**; therefore, pulsatile flow commonly appears in the **arterial** circulation.

### Phasic Flow

**Phasic flow** also occurs when blood moves with a variable velocity. Blood accelerates and decelerates as a result of **respiration**; therefore, phasic flow often appears in the **venous** circulation.

### Steady Flow

**Steady flow** occurs when a fluid moves at a constant speed or velocity. Water flowing through a garden hose is an example of steady flow. Steady flow is present in the venous circulation when individuals stop breathing for a brief moment.

## Laminar vs. Turbulent

### Laminar Flow

Laminar flow is when the flow streamlines are aligned and parallel. The word *lamina* means *layer*. Laminar flow is characterized by layers of blood that travel at individual speeds.

Laminar flow patterns are commonly found in **normal** physiologic states.



Fig. 18.1 Flow in this river is laminar.

Laminar flow has two forms (see Fig. 18.2):

- **Plug flow** occurs when all of the layers and blood cells travel at the same velocity.
- **Parabolic flow** has a bullet-shaped profile. Velocity is highest in the center of the lumen, and gradually decreases to its minimum at the vessel wall.

Both plug and parabolic patterns are laminar and associated with normal physiology. Laminar flow is silent flow.

The **Reynolds number** predicts whether flow is laminar or turbulent. The Reynolds number for laminar flow is less than 1,500.

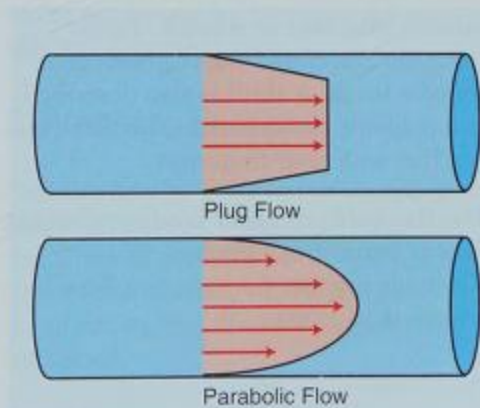


Fig. 18.2 Laminar flow patterns are plug (upper) or parabolic (lower).



### Turbulent Flow

**Turbulent flow** is characterized by chaotic flow patterns in many different directions and at many speeds. The streamlines are often obliterated (see Fig. 18.4).

Small, hurricane-like, swirling, rotational patterns appear in turbulent flow. This is called an eddy current or a vortex.

Turbulence is often associated with cardiovascular **pathology** and elevated blood velocities. Turbulent flow profiles may be seen downstream from a significant stenosis in a vessel.

Turbulent flow converts flow energy into other forms such as sound and vibration. Sound associated with turbulence is called a **murmur** or a **bruit**. Tissue vibration associated with turbulence is called a **thrill**. A thrill is also described as a palpable murmur, which is one you can feel with your fingertips.

The **Reynolds number** predicts whether flow is laminar or turbulent. The Reynolds number for turbulent flow is greater than 2,000.



Fig. 18.3 Flow in this waterfall is turbulent.



Fig. 18.4 Turbulent flow profiles are chaotic.

## Energy Gradient

*Why does blood move from one location to another?*

Blood moves from regions of higher energy to lower energy. This is called an **energy gradient**. This answer may surprise you, because many of us incorrectly believe that blood moves from regions of higher pressure to regions of lower pressure. Pressure is one form of energy; however, there are other forms of energy as well. The significance of an energy gradient will soon be apparent.

*What event provides energy to the circulating blood?*

Energy is imparted to blood by the contraction of the heart during systole.

## Forms of Energy

Several forms of energy are associated with blood:

1. kinetic
2. pressure
3. gravitational

The total energy at a specific location within the circulation is the sum of all three energy forms.

### 1. Kinetic Energy

Kinetic energy is associated with a moving object.

Kinetic energy is determined by two factors:

- an object's mass
- the speed at which it moves

Thus, heavy, swiftly moving objects have lots of kinetic energy. Light, slowly moving objects have little kinetic energy.

#### Example

When a ping-pong ball strikes a window, the ball bounces away harmlessly. When a golf ball traveling at the same velocity strikes the window, it shatters. The golf ball's kinetic energy is greater than that of the ping-pong ball because the golf ball has a greater mass.

### 2. Pressure Energy

Pressure energy is a form of **stored or potential energy**. Potential energy has the ability to perform work. Pressure is a major form of energy for circulating blood and creates flow by overcoming resistance.

#### Example

A can of whipped cream is pressurized. When the valve is opened, the pressure energy propels the cream out of the can. When the pressure in the can diminishes, so too, does the cream's flow.

### 3. Gravitational Energy

Like pressure, gravitational energy is a form of **stored or potential energy**. Gravitational energy is associated with any elevated object. All elevated objects have stored energy (gravitational energy) that can perform work. Identical objects at the same height have the same gravitational energy.

#### *Example*

A downhill skier at the top of a mountain has gravitational energy and glides effortlessly to the bottom of the mountain. In contrast, a cross-country skier on a flat surface has no gravitational (stored) energy and must provide his own muscular energy to move about.

## Energy Losses in the Circulation

As blood flows through the circulation, energy is lost in three ways:

1. viscous loss
2. frictional loss
3. inertial loss

### 1. Viscous Energy Loss

**Viscosity** describes the thickness of a fluid. Honey is viscous, whereas alcohol is not. More energy is lost with movement of high viscosity fluids. Viscous loss is associated with blood overcoming its internal stickiness.

Viscosity is measured in units of **Poise**.

Viscous energy loss in blood is determined by the hematocrit.

**Hematocrit** is the percentage of blood made up of red blood cells. A normal value is approximately 45%. With anemia, hematocrit is reduced, and blood has a reduced viscosity.

### 2. Frictional Energy Loss

Frictional losses occur when flow energy is converted to heat as one object rubs against another. Blood sliding across vessel walls creates heat, and is an example of frictional loss.



### 3. Inertial Energy Loss

Sir Isaac Newton stated that “objects at rest tend to stay at rest and objects in motion tend to stay in motion.” In other words, energy is lost when the speed of a fluid changes, regardless of whether the fluid speeds up (accelerates) or slows down (decelerates).

**Inertia** relates to the tendency of a fluid to resist changes in its velocity.

Inertial energy loss occurs during three events:

- pulsatile flow (usually found in the *arterial* circulation)
- phasic flow (usually found in the *venous* circulation)
- velocity changes at a *stenosis*

Velocity increases as the vessel narrows. Maximum velocity exists where the vessel is narrowest.

Velocity decreases as blood flows out of the stenosis into a vessel segment of normal diameter.

## Stenosis

A **stenosis** is a narrowing in the lumen of a vessel (see Fig. 18.5 and Fig. 18.6).

Stenosis may have these effects on blood flow:

- changes in direction as blood flows into and out of the narrow portion of the vessel.
- increased velocity within the stenosis. Velocity is highest where the vessel is narrowest.
- turbulence downstream from the stenosis, called **post-stenotic turbulence**. In the post-stenotic region, the lumen expands more dramatically than the streamlines of blood flow are able to fill it. The streamlines are destroyed and turbulence, in the form of eddy currents and vortices, appears. Flow energy may be converted to sound (bruit or murmur) or tissue vibration (thrill), or both.
- pressure gradient across the stenosis. The pressure downstream from the stenosis is lower than the pressure upstream. This post-stenotic pressure decrease results from the loss of energy as blood moves through the stenosis.
- conversion of pulsatile flow patterns to steady flow.

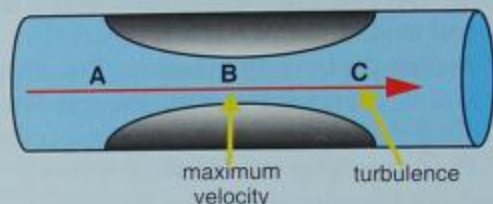


**Fig. 18.5** Stenosis in a vessel. Locations A, B, and C will be used to illustrate Bernoulli's Principle on the next page.



**Fig. 18.6** Ultrasound scan of a stenotic vessel.

**Table 18.1** Hemodynamics of a Stenosis

| Effects of a Stenosis                     |
|-------------------------------------------|
| • change in flow direction                |
| • increased velocity as vessel narrows    |
| • turbulence downstream from the stenosis |
| • pressure gradient across the stenosis   |
| • loss of pulsatility                     |

## Bernoulli's Principle

**Bernoulli's Principle** describes the relationship between velocity and pressure in a moving fluid. Bernoulli's Principle is derived from the principle of conservation of energy. This principle states that, with a steady flow, the sum of all forms of energy is the same everywhere. Simply stated, the sum of kinetic energy and pressure energy remains constant.

In Fig. 18.5 on the facing page, three locations are identified. Location A is before the stenosis, location B is the narrowest part of the vessel, and location C is downstream from the stenosis.

**Where is the pressure lowest, at location A, B, or C?**

**The pressure is lowest at location B.**

The Law of Conservation of Energy states that energy is neither created nor destroyed; it is simply converted from one form to another.

We have previously learned that the velocity of blood is highest at the narrowest part of the vessel, the stenosis (location B). Kinetic energy is associated with a moving object and kinetic energy increases with higher velocities. Therefore, the kinetic energy of blood increases as it speeds up through the stenosis from location A to location B.

Since kinetic energy increases, another form of energy, in this case pressure, simultaneously decreases. Pressure energy is converted into kinetic energy as the blood accelerates. As a result, pressure energy drops within the stenosis and is lowest at location B.

As blood moves to location C, the blood slows. With slower velocity, kinetic energy is reduced. Kinetic energy is converted back into pressure energy as the blood decelerates. As a result, pressure energy rises in the post-stenotic region.

The Law of Conservation of Energy explains why the pressure energy is lowest wherever the kinetic energy is the highest, at the narrowest part of the lumen. This specialized form of the Law of Conservation of Energy is called Bernoulli's Principle.



## Pressure–Flow Relationships

The study of blood flow in the circulation is complex. The elastic nature of vessels, composition of blood, and pulsatile nature of heart pumping all contribute to this complexity. However, some of the pressure–flow relationships may be understood more easily with a simplified system.

The relationship between flow, resistance, and pressure gradient is defined by the following equation:

$$\text{pressure gradient} = \text{flow} \times \text{resistance}$$

Pressure gradient increases when either:

- flow increases, *or*
- resistance increases

Flow increases when either:

- pressure gradient increases, *or*
- resistance decreases

## Ohm's Law

The movement of fluid through a tube and the movement of electricity through a wire are similar. Different terms, however, are used to describe fluid and electrical systems.

We just learned that for a fluid:

$$\text{pressure gradient} = \text{flow} \times \text{resistance}$$

With an electrical system, the same relationship is described by Ohm's Law:

$$\text{voltage} = \text{current} \times \text{resistance}$$

Thus, **pressure** in a fluid system is called **voltage** in an electrical system. Similarly, **flow** in a fluid system is called **current** in an electrical one. **Resistance** has the same name in both systems.

Table 18.2 Comparison of Fluid and Electrical Systems—Ohm's Law

| Fluids       | Electricity         |
|--------------|---------------------|
| • pressure   | • voltage           |
| • flow       | • current           |
| • resistance | • resistance (ohms) |

**Hint:** Electrical resistance is reported in units of **ohms**.

**Hint:** In the circulatory system, the resistance vessels are called **arterioles**.

## Venous Hemodynamics

Veins are thin-walled and collapsible. During normal function, veins have low pressure, are only partially filled with blood and, therefore, only partially expanded (see Fig. 18.7). The cross-sectional shape of a vein during normal function is flattened or hourglass shaped.

### *What is the typical resistance of veins?*

Veins, like arteries, are usually low-resistance vessels. In fact, normal venous resistance and arterial resistance are similar.

### *How do veins adapt to increased inflow during periods of exercise?*

Although considered passive vessels warranting little discussion, veins function in a remarkable way during periods of increased flow.

When venous inflow increases during exercise, the cross-sectional shape of a vein changes from hourglass to oval and then to round. This allows veins to accommodate a large volume increase with a very small increase in pressure.

As veins become more round, the resistance to flow decreases, thereby increasing outflow toward the heart. Veins empty rapidly and then return to their typical semi-collapsed state. Thus, normal veins increase flow with only a small increase in pressure.

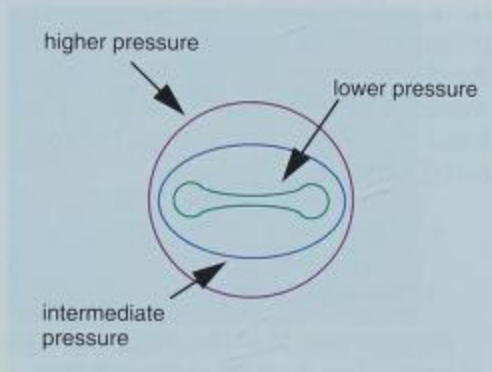


**Fig. 18.7** The cross-section of a vein is hourglass shaped. The shape becomes more circular as the venous pressure increases.

## Hydrostatic Pressure

Have you ever noticed the sensation of pressure on your ears when you dive to the bottom of a swimming pool? The source of this sensation is the weight of water pressing on your eardrum and is called **hydrostatic pressure**.

### Hydrostatic Pressure

pressure related to the weight of blood pressing on a vessel measured at a height above or below heart level.

#### Units

Hydrostatic pressure is reported in units of mmHg, the same units used to measure blood pressure.

The significance of hydrostatic pressure in clinical medicine is demonstrated when measuring a patient's blood pressure. We must ask the question: *Does the measured pressure accurately represent the true circulatory pressure or is there an error related to the location of measurement?*

Hydrostatic pressure introduces an error in measurement based on the site of measurement. Pressures are accurately assessed when the measurement is made at the level of the heart. Pressures are erroneously too high when the measurement is made at a location below heart level. Similarly, measurements are erroneously too low when made at locations above heart level.



## The Supine Individual

**Supine** means flat on your back. When a person is supine, all parts of the body are at the same level as the heart, and the **hydrostatic pressure is zero everywhere**. A pressure measured anywhere on the supine patient accurately represents true circulatory pressure (see Fig. 18.8).



**Fig. 18.8** When supine, hydrostatic pressure is zero everywhere since all vessels are at the same level as the heart.

**Table 18.3 Hydrostatic Pressure in the Supine Patient with a Blood Pressure of 140 mmHg**

| Measurement Site | Blood Pressure | Level | Hydrostatic Pressure | Measured Pressure  |
|------------------|----------------|-------|----------------------|--------------------|
| ankle            | 140 mmHg       | heart | 0 mmHg               | 140 mmHg (140 + 0) |
| knee             | 140 mmHg       | heart | 0 mmHg               | 140 mmHg (140 + 0) |
| mid chest        | 140 mmHg       | heart | 0 mmHg               | 140 mmHg (140 + 0) |
| top of head      | 140 mmHg       | heart | 0 mmHg               | 140 mmHg (140 + 0) |

## Hydrostatic Pressure: Supine

**Arterial blood pressure measured in a supine patient's arm is 140 mmHg.**

- |                                                                                           |                                                                                                                                                                         |
|-------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. What is the hydrostatic pressure at all locations within the arterial circulation?     | 1. With supine individuals, all arteries are at the same level as the heart. Thus, the hydrostatic pressure throughout the arterial circulation is 0 mmHg.              |
| 2. What is the arterial pressure at the knee of the supine patient?                       | 2. 140 mmHg. Since the knee is at the same level as the heart, hydrostatic pressure is 0 mmHg, and the measured pressure at the knee equals the pressure at the heart.  |
| 3. What is the arterial pressure in the carotid artery of the neck of the supine patient? | 3. 140 mmHg. Since the neck is at the same level as the heart, hydrostatic pressure is 0 mmHg. The measured pressure equals the true circulatory pressure at the heart. |

## The Standing Individual

As seen in Fig. 18.9, the reference level in an upright individual is at the heart where hydrostatic pressure is zero. At heart level, the measured pressure accurately represents true circulatory pressure.

At locations below heart level, such as the ankle, hydrostatic pressure is positive. The measured pressure will be higher than the true circulatory pressure.

At locations above the level of the heart, such as the ear, hydrostatic pressure is negative. The measured pressure will be lower than the true circulatory pressure.

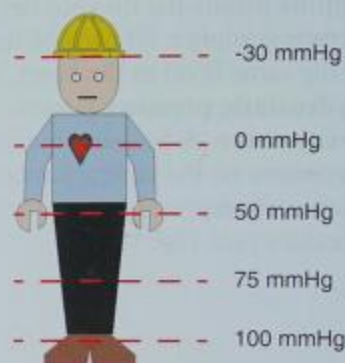


**Fig. 18.9** When standing, hydrostatic pressure depends upon whether the measurement is made above or below heart level.

$$\text{measured pressure} = \text{circulatory pressure} + \text{hydrostatic pressure}$$

**Table 18.4 Hydrostatic Pressure while Standing**  
Upright in a Patient with a Blood Pressure of 140 mmHg

| Measurement Site | Blood Pressure | Level                 | Hydrostatic Pressure | Measured Pressure    |
|------------------|----------------|-----------------------|----------------------|----------------------|
| ankle            | 140 mmHg       | far below heart level | 100 mmHg             | 240 mmHg (140 + 100) |
| knee             | 140 mmHg       | somewhat below heart  | 75 mmHg              | 215 mmHg (140 + 75)  |
| waist            | 140 mmHg       | slightly below heart  | 50 mmHg              | 190 mmHg (140 + 50)  |
| mid chest        | 140 mmHg       | heart level           | 0 mmHg               | 140 mmHg (140 + 0)   |
| top of head      | 140 mmHg       | above heart           | - 30 mmHg            | 110 mmHg (140 - 30)  |

## Hydrostatic Pressure: Standing

**The arterial blood pressure generated by the heart in a patient who is standing upright is 140 mmHg.**

- |                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. What is the hydrostatic pressure at all locations within the arterial circulation?                         | <p>1. The hydrostatic pressure depends on the location of the vessel. Since the patient is standing, all arteries at heart level will have a hydrostatic pressure of 0 mmHg. Hydrostatic pressure in vessels located</p> <ul style="list-style-type: none"> <li>• below heart level will be positive and range from about 50 mmHg at the waist to about 100 mmHg at the ankle.</li> <li>• above heart level will be negative.</li> </ul> |
| 2. What is the arterial pressure measured in the toe of the upright patient?                                  | <p>2. 240 mmHg. Since the toe is far below heart level, the hydrostatic pressure is 100 mmHg. The circulatory pressure generated by the heart is 140 mmHg. Measured pressure is the sum of the hydrostatic pressure and the circulatory pressure:<br/> <math>100 \text{ mmHg} + 140 \text{ mmHg} = 240 \text{ mmHg}</math>.</p>                                                                                                          |
| 3. What is the arterial pressure measured at this patient's knee?                                             | <p>3. 215 mmHg. Since the knee is somewhat below heart level, the hydrostatic pressure is 75 mmHg. The circulatory pressure is 140 mmHg. Measured pressure is the sum of the hydrostatic pressure and the circulatory pressure:<br/> <math>75 \text{ mmHg} + 140 \text{ mmHg} = 215 \text{ mmHg}</math>.</p>                                                                                                                             |
| 4. What is the arterial pressure measured at the standing patient's waist?                                    | <p>4. 190 mmHg. Since the waist is slightly below heart level, the hydrostatic pressure is in the range of 50 mmHg. The circulatory pressure generated by the heart is 140 mmHg. Measured pressure is the sum of the hydrostatic and circulatory pressures:<br/> <math>50 \text{ mmHg} + 140 \text{ mmHg} = 190 \text{ mmHg}</math>.</p>                                                                                                 |
| 5. What is the arterial pressure measured at the standing patient's upper arm?                                | <p>5. 140 mmHg. Since the upper arm is at heart level, hydrostatic pressure is 0 mmHg. The circulatory pressure generated by the heart is 140 mmHg. Measured pressure is the sum of the hydrostatic pressure and the circulatory pressure:<br/> <math>0 \text{ mmHg} + 140 \text{ mmHg} = 140 \text{ mmHg}</math>.</p>                                                                                                                   |
| 6. What is the arterial pressure measured at the finger when the patient fully extends an arm toward the sky? | <p>6. 90 mmHg. Since the extended finger is well above heart level, hydrostatic pressure is approximately -50 mmHg. The circulatory pressure generated by the heart is 140 mmHg. Measured pressure is the sum of the hydrostatic and circulatory pressures:<br/> <math>-50 \text{ mmHg} + 140 \text{ mmHg} = 90 \text{ mmHg}</math>.</p>                                                                                                 |



## Breathing and Venous Flow

In normal individuals, respiration affects venous flow for two reasons:

- the venous system is low pressure
- muscles responsible for respiration alter pressures in the thorax (the chest cavity) and the abdomen

Breathing affects two venous flows (see Fig. 18.10):

- venous flow in the legs (yellow arrow)
- venous return to the heart, which comprises venous flow from the head, arms, and flow from the inferior vena cava to the heart (blue arrows)

The diaphragm is the muscle responsible for breathing. It is dome-shaped and located between the thorax and the abdomen. The diaphragm moves up and down, alternately changing pressure in the thorax and the abdomen, allowing us to breathe.

### Inspiration

During inspiration (see Fig. 18.11), the diaphragm moves downward. The chest cavity expands, creating negative pressure in the chest. Negative thoracic pressure creates suction that increases venous return to the heart. Thus, venous flow from the head, arms, and vena cava increases during inspiration.

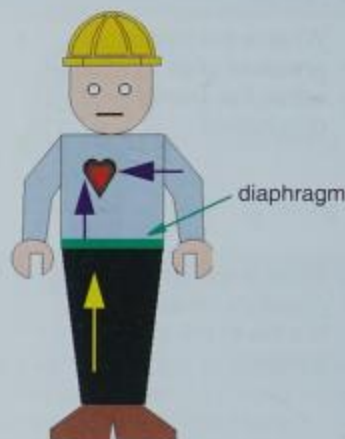


**Fig. 18.10** Venous flow in the legs (yellow arrow) and venous return to the heart (blue arrows).

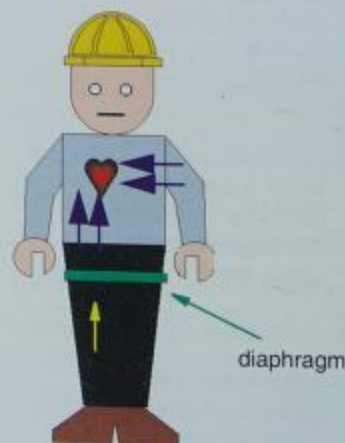


**Fig. 18.11** During inspiration, the diaphragm (green line) descends. Venous return to the heart increases. Venous flow in the legs decreases.

During inspiration, the diaphragm also presses into the abdomen. Abdominal compression increases abdominal pressure and decreases venous blood flow in the legs.

## Expiration

During expiration (see Fig. 18.12), the diaphragm moves upward, increasing pressure in the chest. Increased thoracic pressure reduces venous return to the heart. Thus, venous flow from the head, arms, and the vena cava all decrease during expiration.

Concurrently during expiration, the diaphragm decompresses the abdomen. This decreases abdominal pressure and increases venous blood flow in the legs.

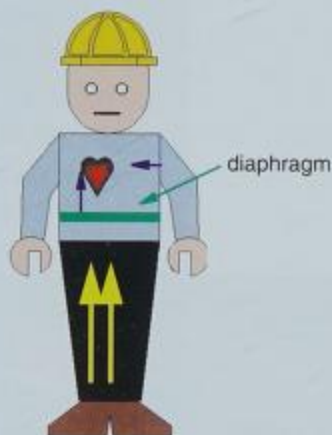


**Fig. 18.12** During expiration, the diaphragm (green line) ascends. Venous return to the heart decreases. Venous flow in the legs increases.

**Table 18.5 Breathing and Venous Flow**

| Inspiration                                   | Expiration                             |
|-----------------------------------------------|----------------------------------------|
| • diaphragm moves downward toward the abdomen | • diaphragm moves upward into thorax   |
| • thoracic pressure decreases                 | • thoracic pressure increases          |
| • abdominal pressure increases                | • abdominal pressure decreases         |
| • venous return to the heart increases        | • venous return to the heart decreases |
| • venous flow in legs decreases               | • venous flow in legs increases        |

**Note:** Venous flow in the legs correlates with movement of the diaphragm.

- Downward movement of the diaphragm (inspiration) decreases venous flow in the legs (downward→decrease).
- Upward movement of the diaphragm (expiration) increases venous flow in the legs (upward→increase).

In contrast, changes in venous return to the heart are opposite to those of venous flow in the legs.

- When venous flow in the leg decreases, venous return to the heart increases.
- When venous flow in the leg increases, venous return decreases.

## Breathing and Venous Flow

| Questions                                                                                                                                                                                                                                | Answers                                                                                                                                                                         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. Normally, what happens to venous flow in the legs during inspiration?<br>A. increases<br>B. decreases<br>C. no change                                                                                                                 | 1. B. During inspiration, venous flow in the legs decreases.                                                                                                                    |
| 2. All of the following occur during expiration <i>except</i> :<br>A. venous return to the heart decreases<br>B. venous flow in the legs increases<br>C. abdominal pressure increases<br>D. the diaphragm rises into the thoracic cavity | 2. C. During expiration, abdominal pressure does not increase; it decreases. Recall that during expiration, the diaphragm ascends into the thorax and decompresses the abdomen. |



# Doppler

Have you ever been standing on a street corner when a motorcycle passes? The zooming noise from the engine seems to increase in frequency or pitch as the motorcycle approaches and decrease in frequency as the motorcycle departs. The change in frequency is due to the Doppler shift. Doppler shift is also called **Doppler frequency**.

Relative motion between the sound source and the receiver creates a frequency change. In other words, the frequency of sound changes when the sound source and the receiver move **closer together or farther apart**. The frequency does not change when the distance between the sound source and receiver remains constant.

This physical principle is used to measure the velocity of blood in the circulation (see Fig. 19.1).

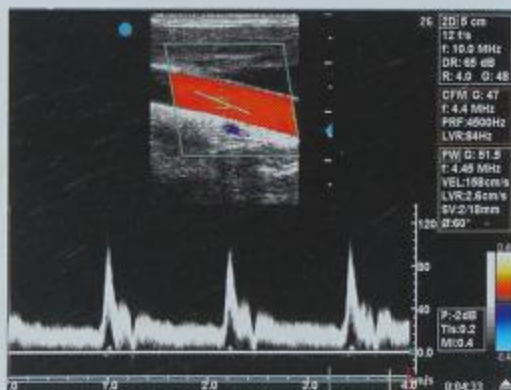


**Fig. 19.1** The Doppler principle is used to measure red blood cell velocities.

The Doppler shift is a low frequency that “rides” on top of the much higher transducer frequency. The process of extracting the low Doppler frequency from the transducer’s carrier frequency is called **demodulation**.

For example, during a Doppler examination, sound with a frequency of 5,000,000 Hz is transmitted from the transducer and reflects off of moving red blood cells. The frequency of the reflected signal is 5,003,000 Hz. The Doppler shift, or change in frequency, is +3,000 Hz; the shift is *positive* because the reflected sound has a *higher* frequency than the transmitted sound. When the Doppler shift is positive, blood cells are traveling toward the transducer.

**Note:** Transducer frequencies of 2,000,000 to 10,000,000 Hz (2 MHz to 10 MHz) are used to perform clinical Doppler exams. However, Doppler shifts range from 20 Hz to 20,000 Hz (20 kHz) and are in the range of audible sound.

$$\text{Doppler shift (Hz)} = \text{reflected frequency} - \text{transmitted frequency}$$

## Creation of a Frequency Shift

Doppler shifts are created when transmitted sound waves strike moving red blood cells.

### Positive Doppler Shifts

When blood cells move toward the transducer, the Doppler shift is *positive*—that is, the reflected frequency is *higher* than the transmitted frequency (see Fig. 19.2).



**Fig. 19.2** Blood cells moving toward the transducer reflect sound with a higher frequency.

## Negative Doppler Shifts

When blood cells move away from the transducer, the Doppler shift is *negative*—that is, the reflected frequency is *lower* than the transmitted frequency (see Fig. 19.3).

## Speed vs. Velocity

Doppler frequencies indicate *velocity*, not *speed*.

**Speed**, which is purely a **magnitude**, indicates the distance that a red blood cell moves in 1 second. Thus, speed is simply reported in units of centimeters per second (cm/s), or any distance divided by time.

**Velocity** is defined by a **magnitude and a direction**. Think of velocity as an arrow, where the length of the arrow indicates its magnitude, and the angle at which the arrow points indicates its direction.

### Example

An automobile is traveling from New York to Florida at a rate of 50 miles per hour:

- speed is 50 miles/hour (speed is a magnitude)
- velocity is 50 miles/hour to the south (velocity is a magnitude and a direction)

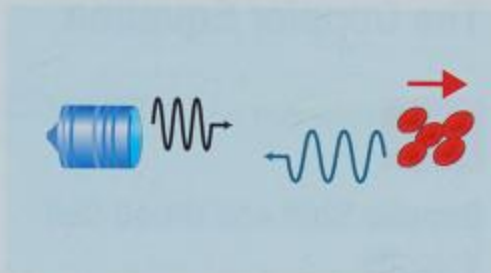


**Fig. 19.3** Blood cells moving away from the transducer reflect sound with a lower frequency.



## The Doppler Equation

$$\text{Doppler shift} = \frac{2 \times \text{velocity of blood} \times \text{transducer frequency} \times \cos \Theta}{\text{propagation speed}}$$

### Doppler Shift and Blood Cell Velocity

*What is the relationship between the velocity of blood and Doppler shift?*

**Doppler shift is directly related to the velocity** of the blood cells. The faster the velocity, the greater the Doppler frequency.

**Example:** Assume that a Doppler study is performed and the Doppler shift is 8 kHz when the blood's velocity is 2 m/s. If the blood velocity slows to 1 m/s, the Doppler shift will be reduced to 4 kHz. When the velocity is halved, the Doppler shift is halved.

*Why is there a "2" in the Doppler equation?*

The "2" represents the fact that there are actually two Doppler shifts during a clinical ultrasound exam:

- The first shift occurs when the sound wave from the transducer strikes moving blood cells. The moving blood's reception of the sound wave is, in itself, sufficient to create a Doppler shift.

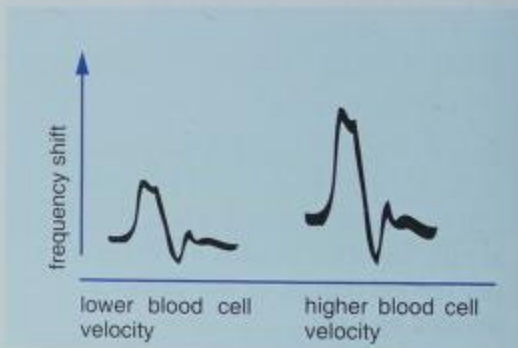


**Fig. 19.4** The Doppler shift is directly related to velocity. When the blood cell velocity doubles, the Doppler frequency doubles.

- After the sound wave strikes blood cells, reflections return to the transducer. The second Doppler shift results from the transducer's reception of the sound wave from moving red blood cells.

## Hertz vs. Centimeters per Second (cm/s)

*If the Doppler shift is measured with units of frequency, how do ultrasound systems report blood velocity?*

Modern ultrasound systems actually measure the **frequency difference** (in hertz) between the received and transmitted sound waves.

However, the Doppler equation is programmed into the ultrasound system's computer. The computer uses the frequency information and the Doppler equation to calculate and display the velocity of blood (see Fig. 19.5).

In other words, the actual data is frequency, with units of Hz. The derived information is velocity, with units of m/s.

This approach is appealing in clinical settings because knowledge that the velocity of blood in an artery is 0.4 m/s has more clinical relevance than knowing the Doppler shift is 3 kHz!

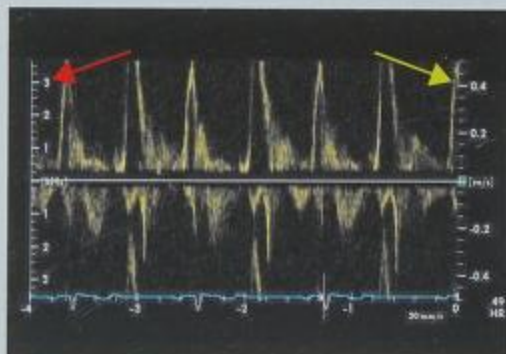


**Fig. 19.5** Spectrum with the Doppler shift scale in kHz on the left side (red arrow). The velocity scale in m/s is on the right side (yellow arrow).

**Hint:** The x-axis of a Doppler spectrum represents time. The y-axis represents Doppler shift or velocity.

## Doppler Shift and Transducer Frequency

*What is the relationship between the transmitted frequency and the Doppler shift?*

Mathematically, the **Doppler shift is directly related to the frequency of the transmitted sound**. In other words, if the transducer's frequency is doubled, the measured Doppler shift will also be doubled (see Fig. 19.6).

**Example:** A Doppler study is performed with a 2 MHz transducer, and the Doppler shift is 3 kHz. If the identical study is performed with a 4 MHz transducer, the Doppler shift will be 6 kHz.

**Note:** The process of calculating velocities from measured Doppler shifts is not obvious to the sonographer because the calculated velocities will be identical, regardless of the transducer frequency.

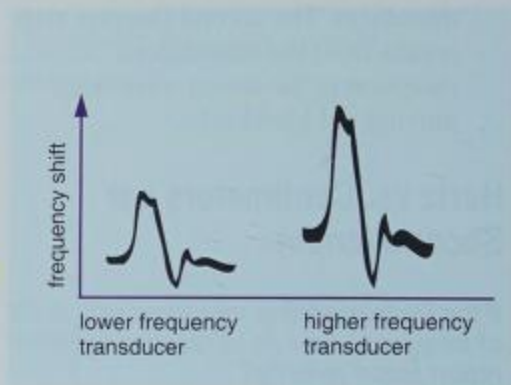


**Fig. 19.6** The Doppler shift is directly proportional to the transducer frequency. When the transmitted frequency doubles, the Doppler frequency doubles.

### Doppler Shift measured in Hertz

- directly related to velocity
- directly related to transducer frequency



## Sound Beam Direction vs. Flow Direction

The measurement of the Doppler frequency depends on the relationship between the direction of blood flow and the direction in which the sound wave propagates.

When the blood cells are moving **parallel** to the sound beam, the entire velocity is measured. That is, when the blood cells are moving either directly toward or directly away from the transducer, the velocity measurement is 100% accurate (see Fig. 19.7).

However, when an angle exists between the direction of flow and the sound beam, the measured velocity is less than the true velocity (see Fig. 19.8).

### Cosine $\theta$

*If the sound beam and flow direction are not parallel, what determines how much of the velocity is measured?*

The percentage of the true velocity that is measured depends on the **cosine of the angle** between the sound beam and the direction of motion. A list of angles and their cosines is found in Table 19.1 on page 310.

$$\text{measured velocity} = \text{true velocity} \times \cos \theta$$

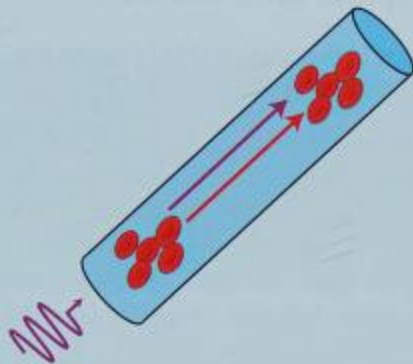


**Fig. 19.7** The Doppler shift represents 100% of the true velocity when blood flow (red arrow) is parallel to the sound beam (purple arrow).

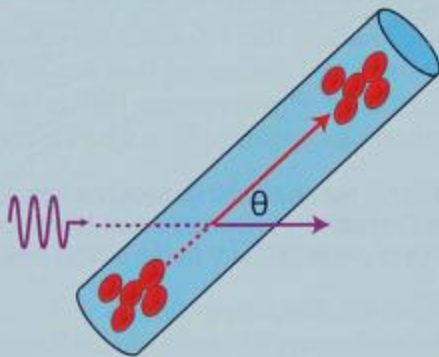


**Fig. 19.8** When there is an angle between the directions of the sound beam and the flow, Doppler measures something less than the true velocity. Note that the length of the purple arrow (measured velocity) is less than that of the red arrow (true velocity).

## Doppler Shift and Cosine $\theta$

*What is the relationship between the cosine  $\theta$  and the Doppler shift?*

Mathematically, the **Doppler shift is directly related to the cosine of the angle between the direction of flow and the direction of sound**. If the cosine  $\theta$  is reduced by half, the measured Doppler shift will be halved (Fig. 19.9).

*What is the relationship between actual velocity and measured velocity when blood moves parallel to the sound beam?*

When the angle between the direction of motion and sound is  $0^\circ$  or  $180^\circ$ , flow is parallel to the sound beam. The measured and true velocities are equal. Cosine  $0^\circ$  is 1, indicating flow *toward* the transducer, whereas cosine  $180^\circ$  is -1, indicating flow *away* from the transducer.

*What is the relationship between actual and measured velocities when blood moves perpendicular to the sound beam?*

When the direction of flow is perpendicular ( $90^\circ$ ) to the sound beam, the measured velocity is zero because the cosine of  $90^\circ$  is zero. Thus, Doppler shifts and velocities cannot be measured with perpendicular incidence.

*What is the relationship between actual velocity and measured velocity when blood moves at a  $60^\circ$  angle to the beam?*

Since the cosine of  $60^\circ$  is 0.5, the measured velocity at  $60^\circ$  is one-half the actual velocity. When blood travels at 2 m/s at a  $60^\circ$  angle to the sound beam, Doppler reports the velocity as 1 m/s.

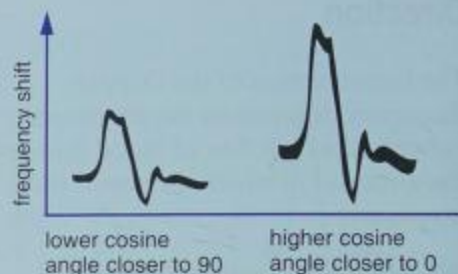


**Fig. 19.9** Doppler shift is directly related to cosine  $\theta$ . When the cosine doubles, the Doppler frequency doubles. The cosine increases as angles approach zero degrees.

**Table 19.1** Cosine of Angles

| Angle (degrees) | Cosine |
|-----------------|--------|
| $0^\circ$       | 1.0    |
| $30^\circ$      | 0.87   |
| $60^\circ$      | 0.5    |
| $90^\circ$      | 0      |
| $120^\circ$     | -0.5   |
| $150^\circ$     | -0.87  |
| $180^\circ$     | -1.0   |

**Note:** At angles other than  $0^\circ$  and  $180^\circ$ , only a portion of the true velocity is measured.

## Bidirectional Doppler

The most common clinical Doppler devices are bidirectional, which distinguish the direction of flow toward or away from the transducer. A **positive** Doppler shift indicates flow *toward* the transducer, whereas a **negative** Doppler shift indicates flow *away* from the transducer.

**Audio of bidirectional Doppler** requires stereo headphones or speakers, where sound from one speaker represents flow toward the transducer and sound from the other speaker represents flow away from the transducer.

Alternatively, the Doppler spectrum can be displayed graphically. Flow toward the transducer is displayed above the baseline, and flow away from the transducer is displayed below the baseline (see Fig. 19.10). **Phase quadrature**, or **quadrature detection**, is a commonly used signal processing technique for bidirectional Doppler.

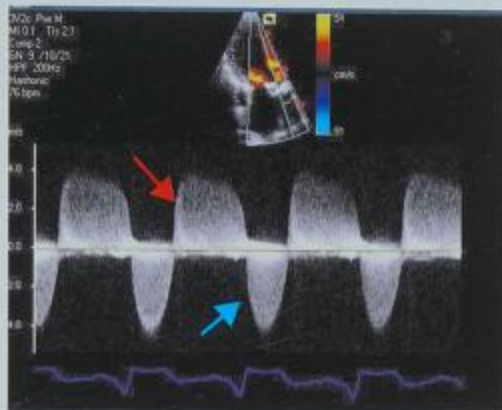


**Fig. 19.10** Bidirectional spectral Doppler tracing. Flow toward the transducer is above the baseline (red arrow). Flow away from the transducer is below the baseline (blue arrow).

**Note:** Blood cells in adjacent arteries and veins typically flow in opposite directions. When these vessels undergo Doppler evaluation, flow from one vessel is heard in the right earphone, and flow from the other vessel is heard in the left. Arterial velocities are higher than venous velocities.



## Continuous Wave Doppler

Continuous wave Doppler requires two crystals in the transducer. One crystal constantly transmits ultrasonic energy, while a second crystal continuously receives reflections from blood cells (see Fig. 19.11).

### Advantage

The greatest advantage of continuous wave Doppler is its ability to accurately measure very high velocities.

### Disadvantages

The primary disadvantage of continuous wave Doppler is that the exact location of the moving blood cells cannot be determined. With continuous wave Doppler, signals arise from all blood cells in the region of overlap between the transmit and receive beams. This limitation is called **range ambiguity** (see Fig. 19.11 and Fig. 19.12).

Another disadvantage of continuous wave Doppler is its lack of time gain compensation (TGC) (see page 226). Reflections created from blood cells located deeper will have a lower amplitude than reflections from blood cells that are at shallower depths. As a result, Doppler shifts produced by deeper blood cells may be incorrectly interpreted as having been created by fewer blood cells.

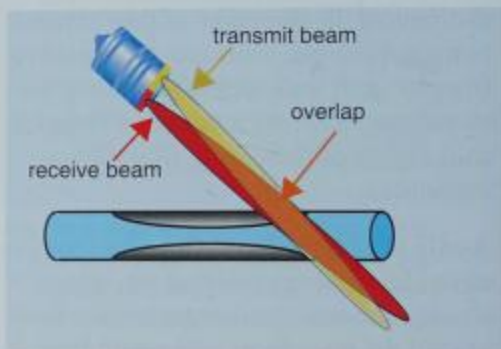


**Fig. 19.11** Continuous wave Doppler uses two transducer crystals, one that transmits (yellow) and one that receives (red). All velocities within the region of overlap (orange) are measured.

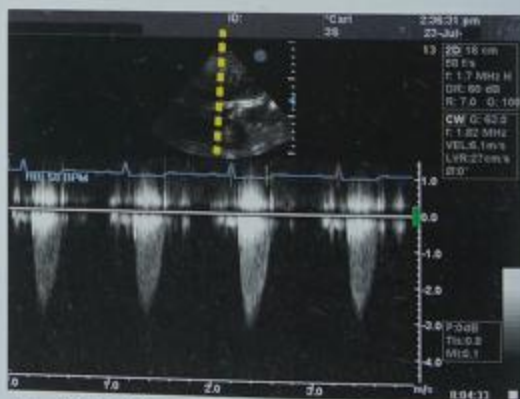


**Fig. 19.12** With continuous wave Doppler, velocities are measured along the entire sound beam (yellow line).

## Continuous Wave Transducers

A **dedicated continuous wave** transducer is relatively simple because it does not create anatomic images. The transducer contains only two elements, each shaped like a semicircle (see Fig. 19.13). One crystal continuously transmits sound while the other receives. Since dedicated continuous wave probes do not create images of anatomy, short duration pulses are unnecessary.

While performing continuous wave Doppler with a conventional imaging array probe, a select group of elements (and the associated electronics) is used for Doppler. Half of the group is excited by continuous electrical signals and transmits a continuous sound beam, while the other half of the group receives the reflected sound. **Simultaneous anatomic imaging and Doppler is called duplex imaging.**

Dedicated continuous wave transducers do not use backing material, which results in the following:

- undampened transmitted signal
- narrow bandwidth
- high quality factor
- higher sensitivity

Matching layers are used in both duplex and dedicated continuous wave transducers. Recall that matching layers increase the efficiency of sound transmitted in and out of the body, which is advantageous in both dedicated continuous wave and duplex Doppler settings.

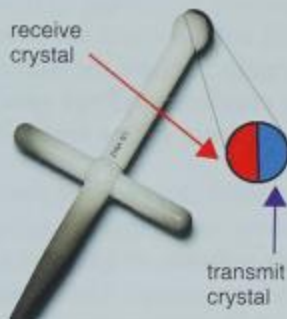


**Fig. 19.13** A dedicated continuous wave Doppler probe is small and has only two elements. Anatomic imaging cannot be performed with this transducer.

**Note:** Most importantly, dedicated continuous wave transducers have increased sensitivity. They detect low amplitude reflections and small Doppler shifts.

## Pulsed Wave Doppler

In pulsed wave Doppler, only one PZT crystal is necessary. The crystal alternates between sending and receiving sound pulses.

### Advantage

The greatest advantage of pulsed Doppler is being able to select the exact location where velocities are measured, called **range resolution, range specificity, or freedom from range ambiguity artifact**.

With pulsed Doppler, the sonographer positions a small marker, called the **sample volume**, or **gate**, on a two-dimensional image. The ultrasound system then calculates the time-of-flight for a sound pulse traveling to and from the gate (see Fig. 19.14 and Fig. 19.15).

The transducer emits a sound pulse and then waits that time-of-flight before briefly listening for a reflection. If the transducer receives an echo during this short listening time, the echo was created at the gate.

### Disadvantages

The primary disadvantage of pulsed Doppler is inaccurate measurement of high velocity signals. High velocity flow in one direction is incorrectly displayed as traveling in the opposite direction. This inaccuracy is called **aliasing**, a false identity (see Fig. 19.16).

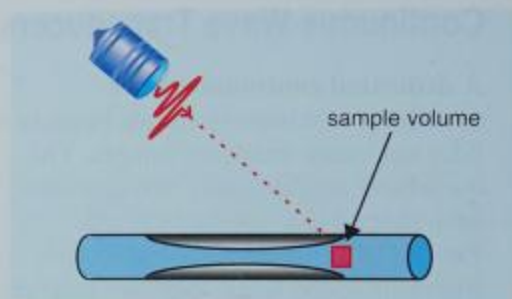


Fig. 19.14 Pulsed wave Doppler measures velocity in a small region, the sample volume.

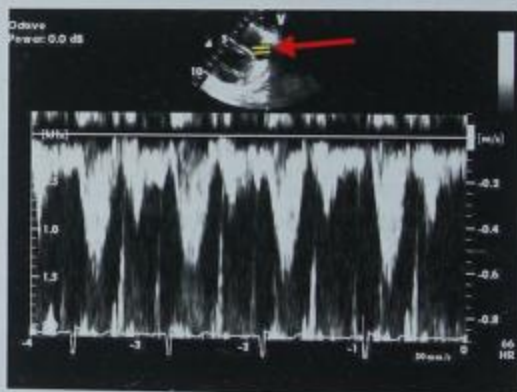


Fig. 19.15 Pulsed wave Doppler spectrum. Velocities are measured from the sample volume (red arrow).

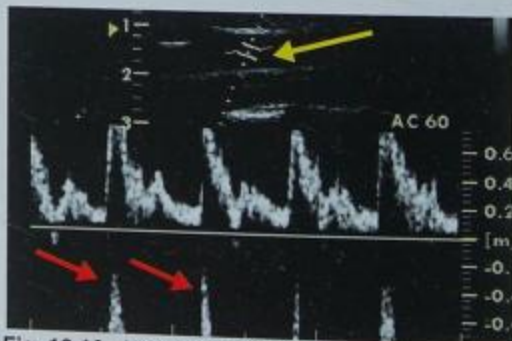


Fig. 19.16 Aliasing artifact (red arrows) appears only with pulsed wave Doppler. The yellow arrow points to the sample volume.



## Pulsed Wave Doppler Transducers

Since imaging and pulsed Doppler are both created from pulsed ultrasound, they can be performed with a single crystal transducer. Studies that simultaneously perform imaging and pulsed Doppler are also called **duplex** examinations. Pulsed Doppler transducers are imaging transducers and contain backing material. They have characteristics similar to those of imaging transducers:

- low quality factor
- lower sensitivity
- wide bandwidth pulses

## Aliasing

Aliasing is the most common error associated with Doppler ultrasound. An alias is a false identity. The false identity in pulsed Doppler is that very high velocities in one direction are incorrectly displayed as going in the opposite direction. In Fig. 19.17, flow is above the baseline, indicating flow toward the transducer. The velocity of these blood cells reaches to the very top of the spectral display, and then incorrectly wraps around and reappears at the very bottom of the display. The very top of the display is called the **Nyquist limit** and the part of the spectrum appearing at the bottom is called **aliasing**.

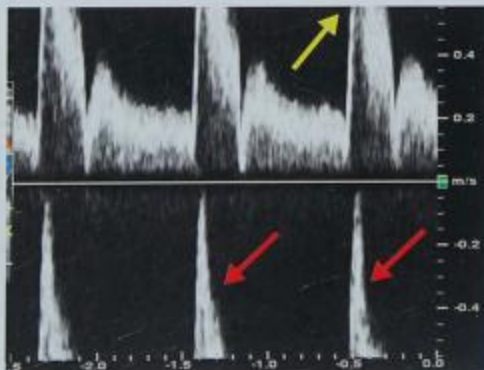


**Fig. 19.17** Aliasing is identified by the red arrows. The yellow arrow points to the Nyquist limit.

The exact same thing can occur in the opposite direction. In Fig. 19.18, blood is flowing away from the transducer and negative velocities appear beneath the baseline. The spectrum reaches the very bottom and then incorrectly wraps around and reappears at the very top. The very bottom of the display is called the Nyquist limit and the part of the spectrum appearing at the top is called aliasing.

### What conditions create aliasing?

- aliasing occurs only with pulsed Doppler, never with continuous wave Doppler
- aliasing occurs when the Doppler sampling rate is too low in comparison to the measured blood velocities

### What is the limit at which aliasing appears and how is it determined?

The Nyquist limit can be thought of as a speed limit. Aliasing appears when the Doppler shift exceeds this speed limit. The Nyquist limit is one-half of the pulse repetition frequency (PRF).

Represented mathematically,

$$\text{Nyquist limit (Hz)} = \frac{\text{PRF (Hz)}}{2}$$

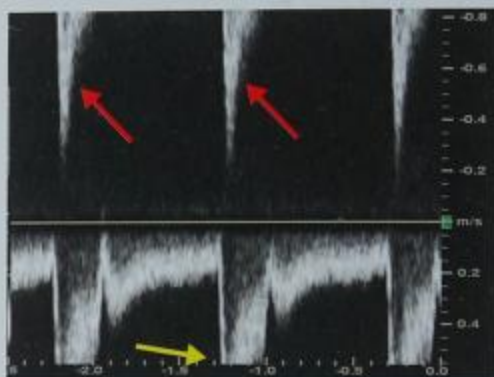


Fig. 19.18 Aliasing is identified by the red arrows. The yellow arrow points to the Nyquist limit.

### Nyquist Limit

The **Nyquist frequency** (or **Nyquist limit**) is the highest Doppler frequency or velocity that can be measured without the appearance of aliasing.

The analogy of a speed limit is helpful here. A penalty is issued when speeding over the limit.

Two ways to avoid the penalty are:

- raise the speed limit
- reduce the speed

To continue the analogy, aliasing (the penalty) appears when the Doppler shift (speed) exceeds the Nyquist limit (speed limit). See Fig. 19.19A.

Two ways to avoid aliasing are:

- raise the Nyquist limit, Fig. 19.19C
- reduce the Doppler shift, Fig. 19.19B

### *How does sample volume depth affect the presence of aliasing?*

With pulsed Doppler, velocities are sampled many times per second. The sampling rate of pulsed Doppler is the system's pulse repetition frequency.

- When the sample volume is deep, the PRF is low and the Nyquist limit is low. Velocity is sampled fewer times each second, and the system is unable to accurately measure high velocities. Deeper sample volumes have a lower pulse repetition frequency and create aliasing, Fig. 19.19A.
- When the sample volume is shallow, the PRF is high, velocity is sampled many times each second, and the Nyquist "speed limit" is high. The system accurately measures high velocities without aliasing, Fig. 19.19C.

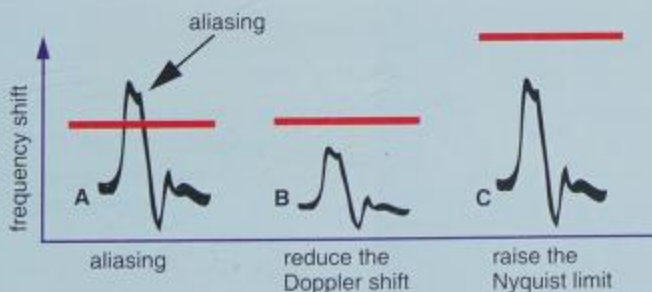


**Fig. 19.19** Aliasing appears (black arrow) when the Doppler shift exceeds the Nyquist limit (red line), image A. Aliasing is eliminated by reducing the Doppler shift, image B. Aliasing is eliminated by increasing the Nyquist limit, image C.



***How does transducer frequency affect aliasing?***

Higher frequency transducers create more aliasing.

You may recall that the Doppler shift is directly related to the transducer's frequency (page 308). The Doppler shift is a percentage of the transducer frequency.

At a particular velocity, higher frequency transducers create higher Doppler shifts (Fig. 19.19A) and lower frequency transducers create lower Doppler shifts (Fig. 19.19B).

Smaller Doppler shifts from lower frequency transducers are less likely to exceed the Nyquist limit. Therefore, aliasing artifacts are less common with lower frequency transducers.

**Table 19.2 Aliasing**

| <b>Less Aliasing</b>                                                         | <b>More Aliasing</b>                                                          |
|------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• slower blood velocity</li></ul>      | <ul style="list-style-type: none"><li>• faster blood velocity</li></ul>       |
| <ul style="list-style-type: none"><li>• lower frequency transducer</li></ul> | <ul style="list-style-type: none"><li>• higher frequency transducer</li></ul> |
| <ul style="list-style-type: none"><li>• shallow gate (high PRF)</li></ul>    | <ul style="list-style-type: none"><li>• deep gate (low PRF)</li></ul>         |

## Thoughts on Aliasing

Five techniques may be used to avoid aliasing artifact:

1. Adjust the scale to its maximum.
2. Select a new ultrasonic view with a shallower sample volume.
3. Select a lower frequency transducer.
4. Use baseline shift.
5. Use continuous wave Doppler.

Each has advantages and disadvantages.

### 1. Adjust scale to its maximum.

Under some circumstances, the system creates pulses at **less than** its maximum allowable rate—in other words, the PRF is not maximized (Fig. 19.20).

When the sonographer adjusts the scale to its maximum, the system's PRF is also increased to its maximum. When the PRF is increased, so is the Nyquist limit (Fig. 19.21).

#### Advantages

Maximizing pulse repetition frequency raises the Nyquist (speed) limit and aliasing is less likely to appear.

#### Disadvantages

Higher pulse repetition frequency reduces sensitivity to low velocities. In addition, with very high velocities, aliasing artifact persists, even when the scale is maximized.

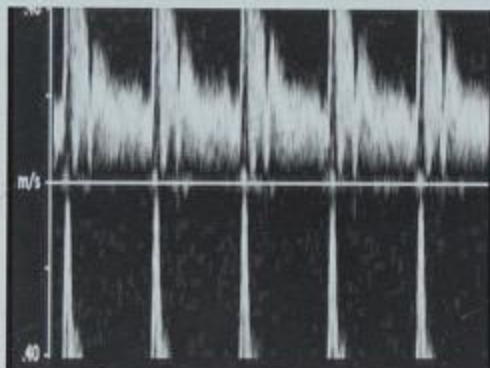


**Fig. 19.20** Doppler spectrum with aliasing. The PRF is lower than its theoretical maximum and the Nyquist limit is low.

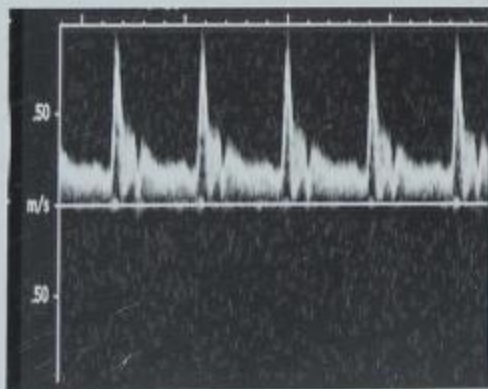


**Fig. 19.21** Doppler spectrum with an increased scale. Aliasing is no longer present because the PRF is high.

## 2. Select a new ultrasonic view with a shallower sample volume.

### Advantages

When the sonographer repositions the transducer to a new view with a shallower sample volume, the PRF is increased. When the PRF is increased, the Nyquist limit is increased and aliasing is reduced.

It is important to realize that even when the transducer is repositioned, the sample volume must still be placed within the anatomic location of clinical interest.

You may have noticed that Fig. 19.22 and Fig. 19.23 are identical to Fig. 19.20 and Fig. 19.21. This is intentional. Increasing the scale and moving to a new view with a shallower sample volume do the same thing—increase the PRF. The difference is in how the PRF is increased.

When the PRF has been set artificially low, increasing the scale can eliminate aliasing. The sonographer leaves the transducer and the sample volume unchanged and simply increases the PRF.

A new view with a shallower sample volume eliminates aliasing as well. The old view had too deep a sample volume. The transducer is moved to a different location which displays the clinical region of interest at a shallower depth. A shallower sample volume increases the PRF.

### Disadvantages

**None.** This technique succeeds if the sonographer can locate an alternative transducer position where the anatomic site is shallower.

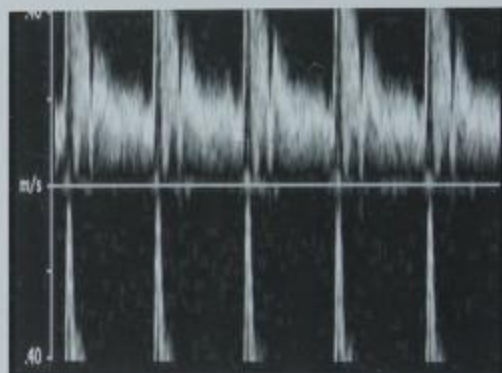


**Fig. 19.22** Doppler spectrum with aliasing. The Nyquist limit is low because the sample volume is deep.

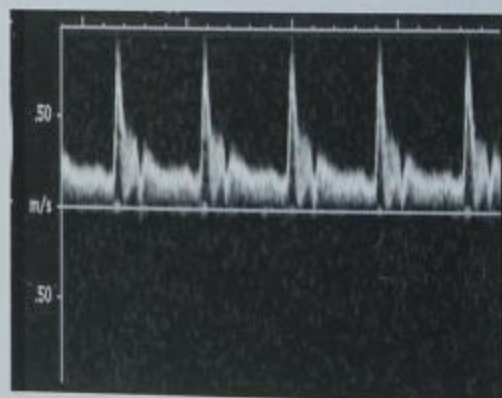


**Fig. 19.23** Doppler spectrum without aliasing. The Nyquist limit is high because the sample volume is shallow.



### 3. Select a lower frequency transducer.

#### Advantages

Doppler shift is directly related to the frequency of the transducer. When measured in hertz, at the same velocity, lower Doppler shifts occur with lower frequency transducers (see Fig. 19.24). In other words, lower frequency sound reduces the height of the Doppler spectrum.

Lower shifts are less likely to exceed the Nyquist limit (or speed limit) and therefore are less likely to alias.

#### Disadvantages

No significant disadvantages are associated with the use of lower frequency sound during a Doppler-only examination. However, during duplex ultrasound, simultaneous Doppler and real-time imaging, lower frequency sound produces a lower quality anatomic image.

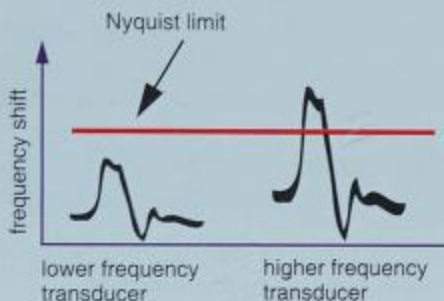


**Fig. 19.24** The Doppler shift is directly related to the transducer frequency. Lower frequency transducers create lower Doppler shifts that are less likely to exceed the Nyquist limit and alias.

#### 4. Use Baseline shift

In the traditional display of bidirectional Doppler, the baseline appears in the middle of the display. Flow toward the transducer is above the baseline, whereas flow away from the transducer is beneath the baseline.

##### *Advantages*

Baseline shift simply slides the display baseline down so that the entire velocity scale is devoted to one direction (Fig. 19.25).

The advantage of zero baseline shift is that high velocity flows are displayed in the proper direction. Although the information remains the same, the display is more pleasing to the eye.

Measurements of maximum velocity remain accurate even after shifting the baseline.

##### *Disadvantages*

Although zero baseline shift changes the visual appearance of flow, little else is accomplished. If audio is used, the sound will still be heard from the incorrect speaker. In addition, baseline shift will be ineffective when the Doppler shift is so high that the signal completely wraps around itself (Fig. 19.26).

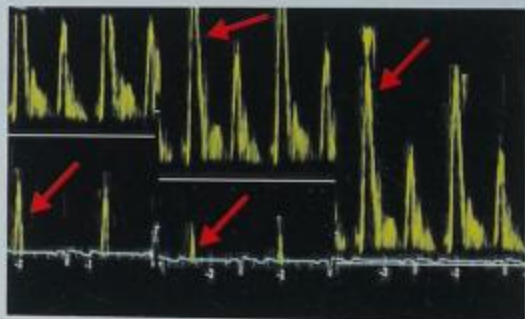


**Fig. 19.25** Shifting the baseline to the bottom eliminates the appearance of aliasing. The high velocities are identified by the red arrows.

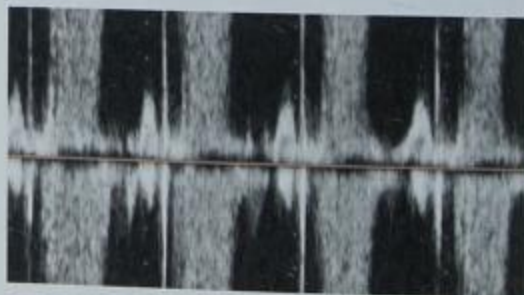


**Fig. 19.26** Zero baseline shift is ineffective when the pulsed Doppler spectrum has wrapped completely around itself.

## 5. Use Continuous Wave Doppler

### Advantages

Aliasing *never* appears with continuous wave Doppler. Aliasing is associated only with pulsed Doppler.

### Disadvantages

Range ambiguity is the primary disadvantage of this technique. With continuous wave Doppler, velocities along the **entire region** of overlap between the transmit and receive beams blend together to form the spectrum. With pulsed Doppler, velocities from blood within the sample volume are measured.

**Hint:** Eliminating aliasing “improves the ability to measure the maximum velocity with Doppler.”

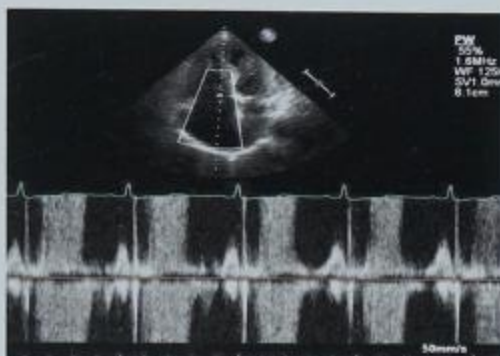


Fig. 19.27 Pulsed Doppler exhibits aliasing with high velocity flow.

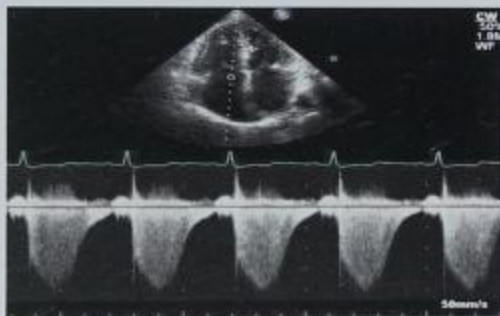


Fig. 19.28 Continuous wave Doppler never aliases.

Table 19.3 Techniques That Eliminate Aliasing

| Method                     | Strategy                                    |
|----------------------------|---------------------------------------------|
| adjust scale               | increases Nyquist limit                     |
| new, shallower view        | increases Nyquist limit                     |
| lower transducer frequency | decreases Doppler shift                     |
| zero baseline shift        | aliasing remains but display more appealing |
| CW Doppler                 | never aliases, but range ambiguity          |



## Gray Shades of a Spectrum

Gray shades on a Doppler spectrum are related to (Fig. 19.29):

- amplitude of the reflected signal  
*or*
- number of blood cells creating the reflection

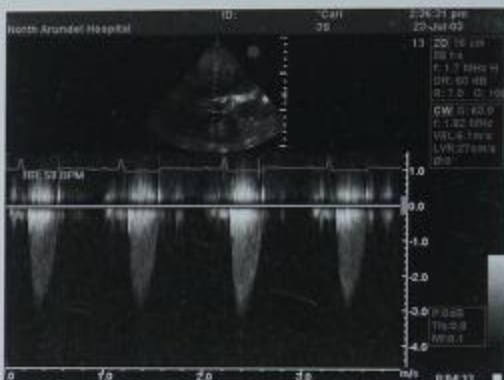


**Fig. 19.29** Gray scale of a Doppler spectrum is related to the number of blood cells.

### Table 19.4 Pulsed vs. Continuous Wave Doppler

| Pulsed Doppler                     | CW Doppler                   |
|------------------------------------|------------------------------|
| • range resolution                 | • range ambiguity            |
| • sample volume                    | • region of overlap          |
| • limited maximum velocity—Nyquist | • unlimited maximum velocity |
| • aliasing                         | • no aliasing                |

Table 19.5 Pulsed vs. CW Transducers

| Pulsed Doppler Transducer | CW Doppler Transducer   |
|---------------------------|-------------------------|
| • at least one crystal    | • at least two crystals |
| • dampened PZT            | • undampened PZT        |
| • low Q-factor            | • high Q-factor         |
| • wide bandwidth          | • narrow bandwidth      |
| • lower sensitivity       | • higher sensitivity    |

Table 19.6 Imaging vs. Doppler

| Imaging                                | Doppler                                 |
|----------------------------------------|-----------------------------------------|
| • normal incidence—90°                 | • 0° or 180°                            |
| • higher frequency—improves resolution | • lower frequency—avoids aliasing       |
| • pulsed wave only                     | • pulsed or CW                          |
| • minimum of 1 crystal                 | • min. of 1 (pulsed) or 2 (CW) crystals |

## Color Flow Doppler

Instead of assessing velocities at a single location (with pulsed Doppler) or along a single transmit line (with CW Doppler), color flow is a form of two-dimensional Doppler. Velocity information is coded into colors and superimposed on a two-dimensional gray scale, anatomic image.

With color Doppler, black-and-white identifies anatomic structures, whereas color identifies blood flow velocities.

Color Doppler provides information on the location of flow and therefore:

- is a pulsed ultrasound technique
- has range resolution (or range specificity)
- is subject to aliasing

Color Doppler provides information regarding direction of flow and is considered semi-quantitative.

Knowledge of the angle between directions of sound and flow is less important with color than with pulsed or continuous wave Doppler.

### Average Velocity

Color Doppler reports **average** or **mean velocities**, whereas pulsed and continuous wave Doppler report **peak velocities**.



Fig. 19.30 Color flow Doppler image.

**Note:** Color Doppler measures mean velocity.

**Spectral Doppler** (pulsed and continuous wave) measures peak velocity.

## Color Maps

Color Doppler uses a “dictionary”, or **lookup table**, to convert measured velocities into colors that appear on the image (see Fig. 19.31). This dictionary is displayed as a vertical bar of various colors, with a black region in the center. The two most commonly used dictionaries are called:

1. velocity mode
2. variance mode

### 1. Velocity Mode

*What do the colors in a velocity mode map mean?*

The colors provide information on **flow direction** and **velocity**. Fig. 19.32 displays two different velocity mode maps.

The black region in the middle of the color map indicates “no Doppler shift.”

The colors *above* the black stripe indicate blood cells moving *toward* the transducer, or **positive** Doppler shifts. If multiple colors appear above the black stripe, then the colors closer to the black stripe indicate lower velocity. Colors at the top indicate ever increasing velocities toward the transducer.

The colors *below* the black stripe indicate blood cells moving *away* from the transducer, or **negative** Doppler shifts.



Fig. 19.31 Color Doppler map.

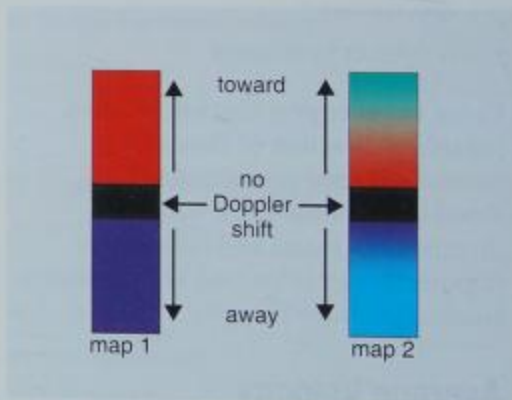


Fig. 19.32 Two different velocity mode maps. Map 1 displays flow direction information, whereas map 2 also displays changes in velocity.



When multiple colors appear below the black stripe, then the colors nearer to the black stripe indicate slower velocity. Colors at the bottom indicate faster velocities away from the transducer.

With velocity mode maps, the color change is always up and down, never side to side.

**Refer to the color maps in Fig. 19.32 to answer the following questions.**

- |                                                                                                                                                                                                                                                                                                                                           |      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1. Which one of the following is true about color map 1?<br>A. Red indicates flow toward the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Blue indicates turbulent flow.<br>D. Blue indicates laminar flow away from the transducer.<br>E. Red indicates turbulent flow.                                          | 1. A |
| 2. Which one of the following is true about color map 1?<br>A. Blue indicates flow toward the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Blue indicates turbulent flow.<br>D. Blue indicates laminar flow away from the transducer.<br>E. Blue indicates flow away from the transducer.                         | 2. E |
| 3. Which of the following is true about color map 2?<br>A. Blue indicates flow toward the transducer.<br>B. Blue indicates flow away from the transducer.<br>C. Light blue indicates turbulent flow.<br>D. Dark blue indicates laminar flow away from the transducer.<br>E. Red indicates turbulent flow.                                 | 3. B |
| 4. Which of the following is true about color map 2?<br>A. Green indicates higher velocity flow toward the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Green indicates higher volume flow toward the transducer.<br>D. Blue indicates laminar flow away from the transducer.<br>E. Red indicates turbulent flow. | 4. A |

## 2. Variance Mode

Variance mode provides more information than velocity mode. In addition to direction and speed information, **variance mode distinguishes laminar flow from turbulent flow** (see Fig. 19.33).

***What do the colors in a variance mode map mean?***

Similar to velocity mode maps, the colors in a variance mode map indicate flow direction. Colors in the *top* half represent blood cells moving *toward* the transducer, while colors in the *bottom* half represent blood cells moving *away* from the transducer.

In addition, the variance maps display different colors side to side. Colors on the left side of the map indicate laminar flow. Laminar flows are typically normal flow patterns.

Colors on the right side of the map indicate turbulent flow. Turbulent flow patterns are often associated with pathology.

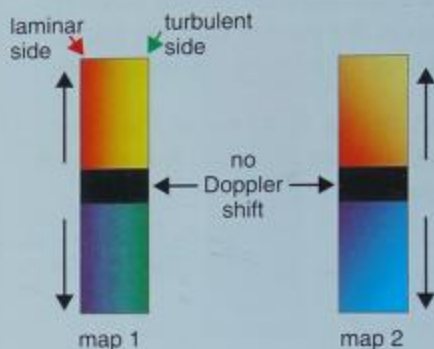


**Fig. 19.33** Two different variance mode maps. Laminar flow appears as colors on the left side of the maps (red and dark blue). Turbulent flow appears as colors on the right side (yellow, green and light blue).

**Hint:** With variance maps, think of the letter L: L is for Left; L is for Laminar.

With variance mode, the colors change side to side as well as up and down.

Use the color maps in Fig. 19.33 to answer the following questions.

|                                                                                                                                                                                                                                                                                                                                          |      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1. Which statement is true about color map 1?<br>A. Red and yellow indicate flow toward the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Blue indicates turbulent flow.<br>D. Green indicates laminar flow away from the transducer.<br>E. Red indicates turbulent flow.                                         | 1. A |
| 2. Which statement is true about color map 1?<br>A. Red and yellow indicate flow away from the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Blue indicates turbulent flow.<br>D. Green indicates turbulent flow away from the transducer.<br>E. Red indicates turbulent flow.                                    | 2. D |
| 3. Which statement is the best reason why color map 1 is a variance mode map?<br>A. Red indicates flow toward the transducer.<br>B. Blue indicates flow away from the transducer.<br>C. Blue and green indicate flow away from the transducer.<br>D. Yellow indicates flow away from the transducer.<br>E. Red indicates turbulent flow. | 3. C |
| 4. Which statement is true about color map 2?<br>A. Light blue indicates flow toward the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Dark blue indicates turbulent flow.<br>D. Dark blue indicates laminar flow away from the transducer.<br>E. Red indicates turbulent flow.                                   | 4. D |
| 5. Which statement is true about color map 2?<br>A. Red indicates turbulent flow toward the transducer.<br>B. Red indicates flow away from the transducer.<br>C. Light blue indicates turbulent flow.<br>D. Light blue indicates laminar flow toward the transducer.<br>E. Red indicates turbulent flow.                                 | 5. C |



## Predicting Flow Directions: Sector Image

The following example illustrates how to determine the direction of flow in a horizontal vessel with a sector image.



**Fig. 19.34** Use this color Doppler image to answer the questions regarding the direction of blood flow in a sector-shaped image.

1. In Fig. 19.34, in which direction does blood flow through the top vessel?

A. left to right  
B. right to left  
C. left to right, then right to left  
D. right to left, then left to right

1. A. left to right.

Follow these steps to determine the direction of flow:

1. With any color flow image that is **sector-shaped**, first examine the color map.
2. Identify the color representing flow toward the transducer, the top color of the map. In this example, the "toward color" is red.
3. Next, identify the "away color" on the map, the bottom color of the map. In this example, the "away color" is blue.
4. Now, look at the vessel. Place your finger in the vessel on the "toward color" and then slide your finger to the "away color": this is the direction of flow in the vessel.

In this example and in the upper vessel, place your finger on the red color and slide it toward the blue color. The direction of flow is from left to right.

2. In Fig. 19.34, what does the black area (yellow arrow) in the center of both vessels represent?

A. no flow  
B. a dissection  
C. a clot  
D. zero Doppler shift  
E. all of the above

2. D, zero Doppler shift.

The angle  $\theta$  (theta) between flow direction and sound beam direction is critically important when interpreting Doppler. The absence of color at the center of the vessel is a result of the direction of flow and the direction of the sound beam being perpendicular. The cosine of  $90^\circ$  is zero.

## Predicting Flow Directions: Rectangular Image

The following example illustrates how to determine the direction of flow in a horizontal vessel with a rectangular image.

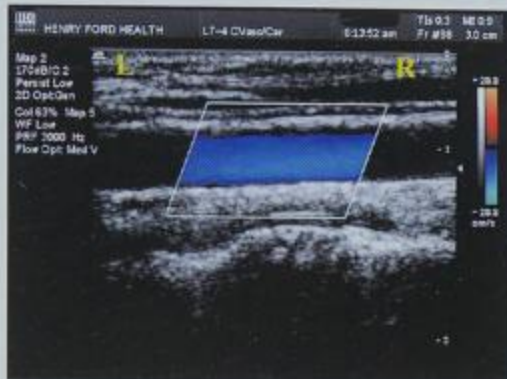


**Fig. 19.35** Use this color Doppler image to answer the question regarding the direction of blood flow in a rectangular image with a steered Doppler box.

In Fig. 19.35, in which direction is blood flowing through the vessel?

- A. left to right
- B. right to left
- C. left to right, then right to left
- D. right to left, then left to right

B. right to left.

Linear transducers produce rectangular images with the Doppler box steered at an angle. A horizontal vessel contains only a single color. Therefore, the technique described previously for sector images will not work.

### Explanation

With a rectangular image, a reference called “home” must be created. Home is an imaginary transducer location within the vessel’s lumen.

With a horizontal vessel, the color box is steered. Look at the two top corners of the color box and draw an imaginary line downward from the corner of the steered box that **does not run into the color**.

This line is positioned on the exterior of the parallelogram shaped color box. The “home line” is the imaginary location of the transducer (see Fig. 19.36).

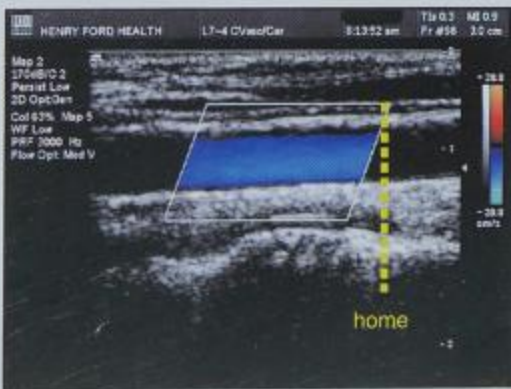


**Fig. 19.36** The “home line” extends downward from the upper corner that is on the exterior of the steered box.

Here, the vessel is blue—the “away color” on this map. Place a finger on the blue color in the vessel and move it *away* from the home line: this is the direction of flow in the vessel.

In this example, your finger moved from the right side of the image to the left side, so in this example, flow is from right to left (see Fig. 19.37).

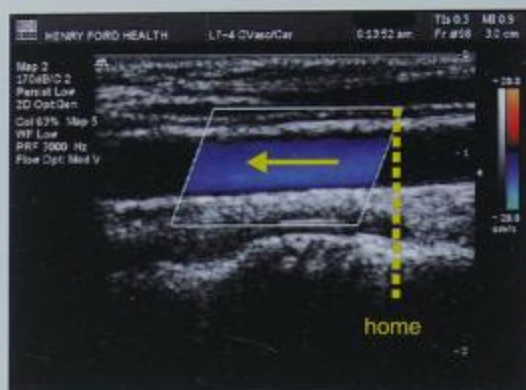


**Fig. 19.37** The “home line” extends downward from the upper corner of the steered box, which does not strike the color.

## Doppler Packets

With color Doppler, multiple ultrasound pulses are used to accurately determine blood velocities. These multiple pulses are called a **packet**, or **ensemble**.

Packets composed of a larger number of pulses (**larger packets** or **longer ensemble lengths**) have two **advantages**:

- more accurate velocity measurement
- increased sensitivity to low flow

Packets with more pulses have these **disadvantages**:

- more time needed to acquire data
- reduced frame rate
- decreased temporal resolution

Packet size should be carefully selected to balance two competing interests of color Doppler: accurate velocity measurements and adequate temporal resolution.



## Power Doppler

Power mode only identifies the presence of a Doppler shift. It does not evaluate speed or direction. Power mode is **non-directional color Doppler**.

In the power Doppler image (see Fig. 19.38), all vessels have the same color, regardless of the direction of blood flow. The image is similar to a Doppler angiogram.

Power Doppler is also called **energy mode** or **color angio**.

More traditional forms of Doppler, such as pulsed, continuous, or color, process velocity information. In power mode, the strength (amplitude) of the reflected signal is processed without regard to the blood's direction or speed. The amplitude of the reflection is directly related to the number of moving blood cells.

Three **advantages** of power mode are:

- increased sensitivity to low flow or velocity, such as venous flow or flow in small vessels
- unaffected by Doppler angles, unless the angle is exactly  $90^\circ$
- no aliasing, since the velocity information is ignored



Fig. 19.38 Color power Doppler is non-directional.

Three **disadvantages** of power mode are:

- no measurement of velocity or direction
- lower frame rates (reduced temporal resolution) than conventional color flow Doppler
- susceptible to motion of the transducer, patient, or soft tissues, which may result in a burst of color, or flash artifact

## Doppler Artifacts

### Ghosting and Clutter

Doppler shifts generally arise from moving blood. However, slowly moving anatomy, such as heart muscle or pulsating vessel walls, may create very low frequency Doppler shifts.

On spectral displays, these low frequency Doppler shift artifacts are called **clutter**. With color Doppler, they are called **ghosting artifact**.

#### *How is clutter or ghosting artifact eliminated?*

A **wall filter** is used to eliminate low frequency Doppler shifts from moving anatomy rather than from moving blood cells. In essence, wall filters serve as a “reject” for Doppler.

Wall filters eliminate low frequency Doppler shifts around the baseline of a spectral display, but have no effect on higher Doppler frequency shifts commonly created by blood cell motion (Fig. 19.39, red arrow). Wall filters are also called **high pass filters**.

With color Doppler, wall filters eliminate color arising from slow velocity reflectors (Fig. 19.40, yellow arrow).

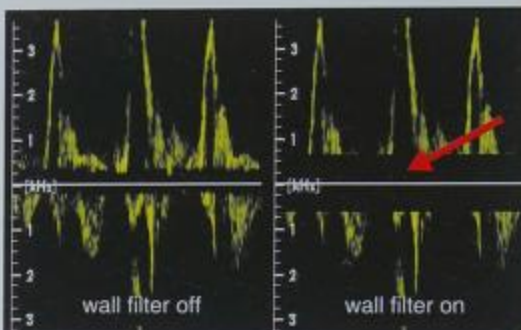


Fig. 19.39 A wall filter eliminates low frequency Doppler signals near the spectral baseline.

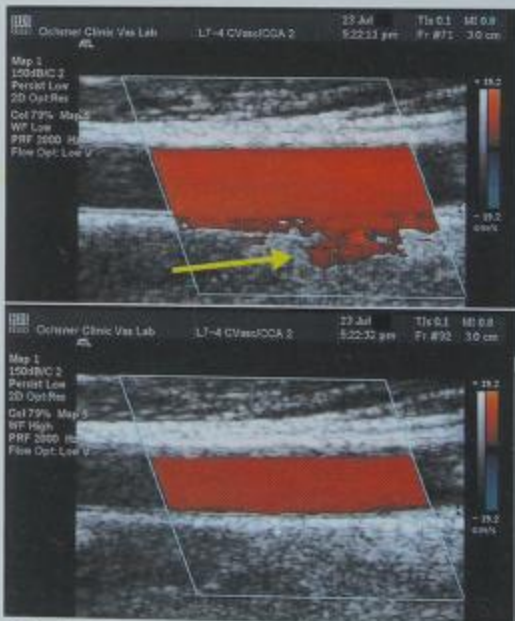


Fig. 19.40 Color “bleeds” (yellow arrow) into moving anatomy with a low wall filter setting (upper). With higher wall filters, low velocity reflectors such as tissue are without color (lower).

## Crosstalk

**Crosstalk**, a special form of “mirror image” artifact, arises only with spectral Doppler. Crosstalk appears as an identical Doppler spectrum both above and below the baseline (see Fig. 19.41). The true flow pattern is unidirectional; however, the flow appears bidirectional on the spectrum.

Generally, crosstalk results from either:

- Doppler gain is set too high (electronic crosstalk), or
- the incident angle is near  $90^\circ$  between the sound beam and the flow direction, when flow is at the beam's focus

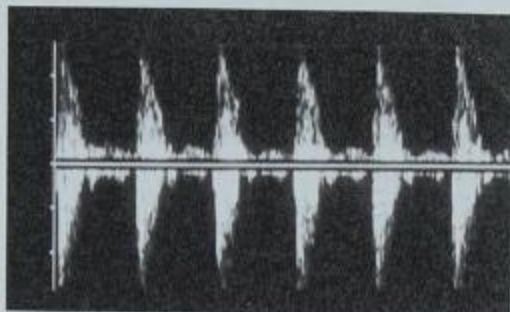


**Fig. 19.41** Crosstalk is a special form of mirror image artifact that appears on a spectral display.

## Spectral Analysis

All blood cells within a sample volume do not travel at the same speed or direction. Many Doppler-shifted frequencies arise from a mass of moving blood cells.

**Spectral analysis** is a tool that breaks the complex signal into its basic “building blocks” and identifies the individual velocities that make up the reflected Doppler signal. This is somewhat similar to identifying the ingredients in a bowl of soup.

Two methods of spectral analysis are currently used:

1. Fast Fourier Transform (FFT)
2. Autocorrelation

Early methods of Doppler analysis, including zero crossing detectors, Chirp-Z transform, and time interval histograms, are now obsolete. These methods were *analog*—that is, they did not use computers. Rather than displaying all of the individual velocity components, only mean velocity was reported.



## 1. Fast Fourier Transform

Fast Fourier Transform (FFT), a digital (computer-based) technique, is used to process both pulsed and continuous wave Doppler signals.

Fast Fourier Transforms have two advantages:

- exceedingly accurate
- displays all individual velocity components that make up the complex reflected signal

**What is the significance of displaying all component frequencies with Fast Fourier Transforms?**

The spectral display of an FFT distinguishes **laminar** flow from **turbulent** flow.

With laminar flow, most blood cells within the sample volume travel at similar velocities. The spectral trace is a narrow, well defined line. The region between the baseline and the spectrum, called the *spectral window*, is clear (see Fig. 19.42).

With turbulence, blood flow is chaotic. Many different directions and speeds are within the sample volume. With turbulent flow, the pulsed Doppler spectral window is filled in. This is known as **spectral broadening**—a wider range of velocities and Doppler shifts within the sample volume (see Fig. 19.43).

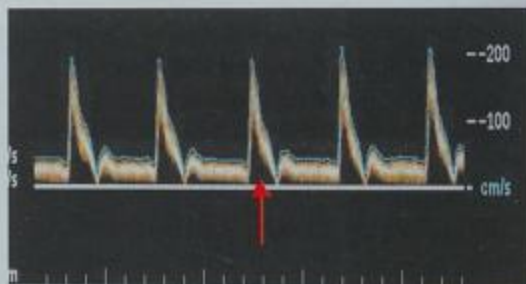


**Fig. 19.42** Laminar flow has a well defined, clear window (red arrow).

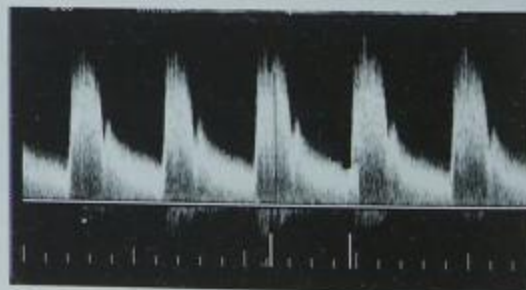


**Fig. 19.43** Spectral broadening, the fill-in of the window, is associated with turbulent flow.

## 2. Autocorrelation

**Autocorrelation or correlation function** is the digital (computer-based) technique used to analyze **color flow Doppler**.

Autocorrelation is used with color Doppler because of the enormous amount of data that is processed. Autocorrelation is somewhat less accurate but substantially faster to perform than Fast Fourier Transforms.

## Summary: Doppler Modality Roles

Table 19.7 Doppler Modalities

| Continuous Wave                                                                                                                     | Pulsed Wave                                                                                  | Color Flow                                                                                                                                        | Power Mode                                                                                          |
|-------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>identifies highest velocity jets anywhere along the length of the ultrasound beam</li> </ul> | <ul style="list-style-type: none"> <li>accurately identifies the location of flow</li> </ul> | <ul style="list-style-type: none"> <li>provides two-dimensional flow information directly on anatomic image</li> </ul>                            | <ul style="list-style-type: none"> <li>used with low velocity or small volume blood flow</li> </ul> |
| <ul style="list-style-type: none"> <li>range ambiguity</li> </ul>                                                                   | <ul style="list-style-type: none"> <li>range resolution</li> </ul>                           | <ul style="list-style-type: none"> <li>range resolution</li> </ul>                                                                                | <ul style="list-style-type: none"> <li>range resolution</li> </ul>                                  |
| <ul style="list-style-type: none"> <li>most sensitive</li> </ul>                                                                    | <ul style="list-style-type: none"> <li>moderately sensitive</li> </ul>                       | <ul style="list-style-type: none"> <li>moderately sensitive</li> <li>size of color jet is most affected by color Doppler gain settings</li> </ul> | <ul style="list-style-type: none"> <li>greater sensitivity than color flow</li> </ul>               |
| <ul style="list-style-type: none"> <li>very good temporal resolution</li> </ul>                                                     | <ul style="list-style-type: none"> <li>very good temporal resolution</li> </ul>              | <ul style="list-style-type: none"> <li>reduced temporal resolution due to multiple packets</li> </ul>                                             | <ul style="list-style-type: none"> <li>lowest temporal resolution</li> </ul>                        |
| <ul style="list-style-type: none"> <li>no aliasing</li> </ul>                                                                       | <ul style="list-style-type: none"> <li>subject to aliasing</li> </ul>                        | <ul style="list-style-type: none"> <li>based on pulsed ultrasound, subject to aliasing</li> </ul>                                                 | <ul style="list-style-type: none"> <li>subject to flash artifact, not to aliasing</li> </ul>        |
| <ul style="list-style-type: none"> <li>peak velocity measurements</li> </ul>                                                        | <ul style="list-style-type: none"> <li>peak velocity measurements</li> </ul>                 | <ul style="list-style-type: none"> <li>mean velocity measurements</li> </ul>                                                                      | <ul style="list-style-type: none"> <li>no velocity measurements</li> </ul>                          |

## Review: Doppler

| Questions                                                                                                                                                                                     | Answers                                                                                                                                                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. The Doppler effect is presented as a ____ when the source and the receiver are ____.                                                                                                       | 1. Frequency shift, in motion relative to each other.                                                                                                                 |
| 2. Starting from the same point, the sound source is moving toward the east at 12 miles/hour and the receiver is moving toward the west at 10 miles/hour. The Doppler shift is ____ [+ or -]. | 2. The Doppler shift is negative because the source and receiver are moving farther apart.                                                                            |
| 3. Starting from the same point, the receiver is moving toward the west at 12 miles/hour and the source is moving toward the west at 10 miles/hour. The Doppler shift is ____ [+ or -].       | 3. The Doppler shift is negative because the source and receiver are moving farther apart.                                                                            |
| 4. Doppler shift produces information about ____.                                                                                                                                             | 4. Velocity.                                                                                                                                                          |
| 5. At what angle between the sound beam and the direction of motion will the Doppler shift be the highest?                                                                                    | 5. $0^\circ$ or $180^\circ$ (The sound beam and the direction of motion should be parallel).                                                                          |
| 6. At what angle between the sound beam and the direction of motion will the Doppler shift be closest to zero?                                                                                | 6. $90^\circ$ . No Doppler frequency exists because the cosine of $90^\circ$ is zero.                                                                                 |
| 7. What is the difference between speed and velocity?                                                                                                                                         | 7. Speed has only a magnitude. Velocity has magnitude and direction.                                                                                                  |
| 8. What is the current method of processing Doppler signals?                                                                                                                                  | 8. The Fast Fourier Transform (FFT) method of spectral analysis is used for pulsed and CW. Autocorrelation is the method of spectral analysis for color flow Doppler. |
| 9. What is the typical range of Doppler shift found in diagnostic imaging examinations?                                                                                                       | 9. Between 20 Hz and 20 kHz (in the audible range).                                                                                                                   |
| 10. The phenomenon where high velocities appear in the opposite direction is called ____.                                                                                                     | 10. Aliasing.                                                                                                                                                         |



| Questions                                                                                                                                                                                                                                                     | Answers                                                                                                                                                                                                                                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 11. The frequency at which aliasing occurs is called ____.                                                                                                                                                                                                    | 11. Nyquist limit.                                                                                                                                                                                                                                              |
| 12. The area of interrogation in a pulsed Doppler exam is called ____.                                                                                                                                                                                        | 12. Sample volume.                                                                                                                                                                                                                                              |
| 13. True or False. The higher the emitted frequency, the more likely a pulsed wave signal is to alias.                                                                                                                                                        | 13. True.                                                                                                                                                                                                                                                       |
| 14. True or False. Shallower sample volumes result in more aliasing.                                                                                                                                                                                          | 14. False.                                                                                                                                                                                                                                                      |
| 15. True or False. Only pulsed wave Doppler exams have a sample volume.                                                                                                                                                                                       | 15. True.                                                                                                                                                                                                                                                       |
| 16. An 8 MHz transducer with a pulse repetition frequency of 5,000 Hz is imaging to a depth of 7 cm. What is the Nyquist frequency?<br>A. 4 MHz<br>B. 3.5 Hz<br>C. 2.2 kHz<br>D. 2.5 dB<br>E. 5 kHz                                                           | 16. C. The actual Nyquist limit is one-half of the pulse repetition frequency, 2.5 kHz or 2,500 Hz.<br><br>In this example, the "perfect" answer does not appear in the choices. In cases such as this, select the answer that is closest to the actual answer. |
| 17. An 8 MHz transducer with a pulse repetition frequency of 5,000 Hz measures a Doppler shift of 7 kHz. The study is repeated with a 4 MHz transducer. What Doppler shift will be measured?<br>A. 4 MHz<br>B. 3.5 Hz<br>C. 4 kHz<br>D. 3.5 dB<br>E. 3,500 Hz | 17. E. The measured Doppler shift is directly related to the transducer frequency.<br><br>In this example, the transducer frequency is halved. The Doppler shift will be halved as well.                                                                        |
| 18. True or False. A successful Doppler exam cannot be performed on a severely anemic patient.                                                                                                                                                                | 18. False. Within the physiologic range, variations in red blood cell concentration will not affect the ability to successfully perform a Doppler exam.                                                                                                         |

| Questions                                                                                                                                                                                                           | Answers                                                                                                                                                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 19. Which technique is used to perform spectral analysis on color Doppler data?<br>A. autocorrelation<br>B. demodulation<br>C. Fast Fourier Transform<br>D. pulse inversion                                         | 19. A. autocorrelation. Autocorrelation is the digital (computer-based) technique used to analyze color flow Doppler.                                                                                       |
| 20. Which technique is used to perform spectral analysis on pulsed Doppler data?<br>A. autocorrelation<br>B. demodulation<br>C. Fast Fourier Transform<br>D. pulse inversion                                        | 20. C. Fast Fourier Transform. The FFT performs spectral analysis on pulsed and continuous wave Doppler data.                                                                                               |
| 21. Which of the following terms is synonymous with spectral broadening?<br>A. plug flow<br>B. parabolic flow<br>C. laminar flow<br>D. turbulent flow                                                               | 21. D. turbulent flow. With turbulent flow, the spectral window is filled-in. A filled-in pattern is called spectral broadening.                                                                            |
| 22. Which of the following is an advantage of a large packet size?<br>A. less aliasing<br>B. increased frame rate<br>C. improved lateral resolution<br>D. increased Doppler accuracy                                | 22. D. increased Doppler accuracy. Doppler is more accurate with larger packets.                                                                                                                            |
| 23. Why are dedicated continuous wave Doppler transducers so sensitive?<br>A. absence of the matching layer<br>B. increased electrical conductance<br>C. absence of backing material<br>D. inclusion of demodulator | 23. C. absence of backing material. A continuous wave transducer does not create anatomic images and does not contain backing material. This increases the sensitivity of dedicated CW Doppler transducers. |
| 24. True or False. The lumen of a horizontal vessel evaluated with a color Doppler, sector shaped image contains a single color.                                                                                    | 24. False. The vessel will have both the toward and away colors. The center of the lumen will be black (see Fig. 19.34).                                                                                    |

## Optimizing Doppler Imaging

Color Doppler has evolved into a primary diagnostic tool. The ability to use color to display flows directly onto a gray scale image provides valuable information for the clinician.

The interpretation of color flow images is not as straightforward as it may seem. There is a great deal of user control in Doppler imaging. Unfortunately, suboptimal or non-diagnostic images can be created. Although pleasing to the eye, color Doppler images demand careful analysis and interpretation.

In this chapter, we will explore how certain system settings affect color Doppler images.

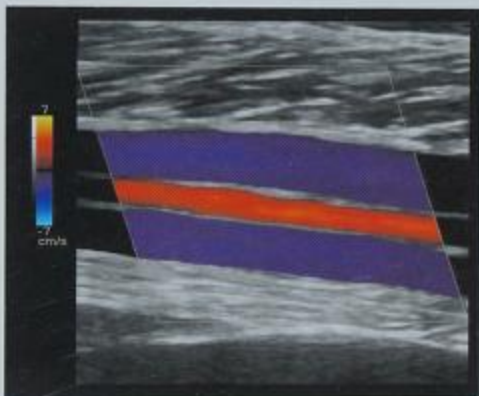


**Fig. 20.1** Color flow Doppler image of vessels in the foot.



**Fig. 20.2** Color flow Doppler of the heart.



## Normal Incidence

*In color Doppler image A in Fig. 20.3, why does the vessel appear without color?*

In this case, the angle between the direction of flow and the direction of the sound beam is 90 degrees. Since the cosine of 90 degrees is zero, no Doppler shift is created or measured, and no color appears in the vessel.

*What will make color appear in this vessel?*

For color to appear in the vessel, an angle other than 90 degrees must be created between the direction of flow and the direction of the sound beam. The cosine of 90 is zero and the cosine changes to a maximum value of 1 at zero degrees or a minimum value of -1 at 180 degrees.

In images B and C, the color box is steered. The angle between flow and sound beam directions is different than 90 degrees, creating color in the lumen of the vessel.

*Other than changing the angle, is there an alternative action that will make color appear in the vessel?*

No. Color will **never** appear in a vessel when the directions of flow and sound are perpendicular. Therefore, any time a vessel is without color, the first thing to do is check the angle between flow and sound.

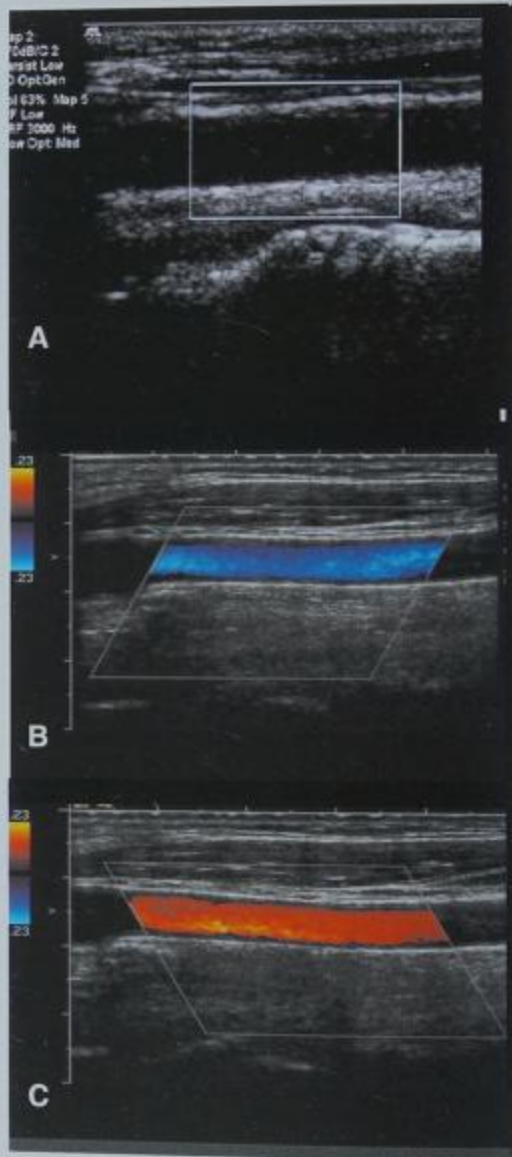


**Fig. 20.3** Three color Doppler images of the same vessel. Color cannot appear when the angle between the direction of flow and sound is 90 degrees.

***In color Doppler image A in Fig. 20.4, why is there no color within the vessel?***

In this case, the angle between the direction of flow and the sound beam is 90 degrees. Since the cosine of 90 degrees is zero, no Doppler shift is measured and no color appears.

This image illustrates that a 90-degree angle between the directions of sound and flow can be created with slanted vessels. The vessel need not be horizontal. In this case, the color box is steered to the left, creating a 90-degree angle with the slanted vessel. The color box does not need to be directed straight downward to create the 90-degree angle.

***What will make color appear in this vessel?***

For color to appear in the vessel, an angle other than 90 degrees must be created between the direction of flow and the direction of the sound beam. The cosine of 90 is zero and the cosine changes to a maximum value of 1 at zero degrees or a minimum value of -1 at 180 degrees.

In images B and C, the angle between flow and sound beam directions is not 90 degrees, creating color in the lumen of the vessel.

***Other than changing the angle, is there an alternative action that will make color appear in the vessel?***

No. Color will never appear in a vessel when the directions of flow and sound are perpendicular. Therefore, any time a vessel is colorless, the first thing to do is check the angle between flow and sound.

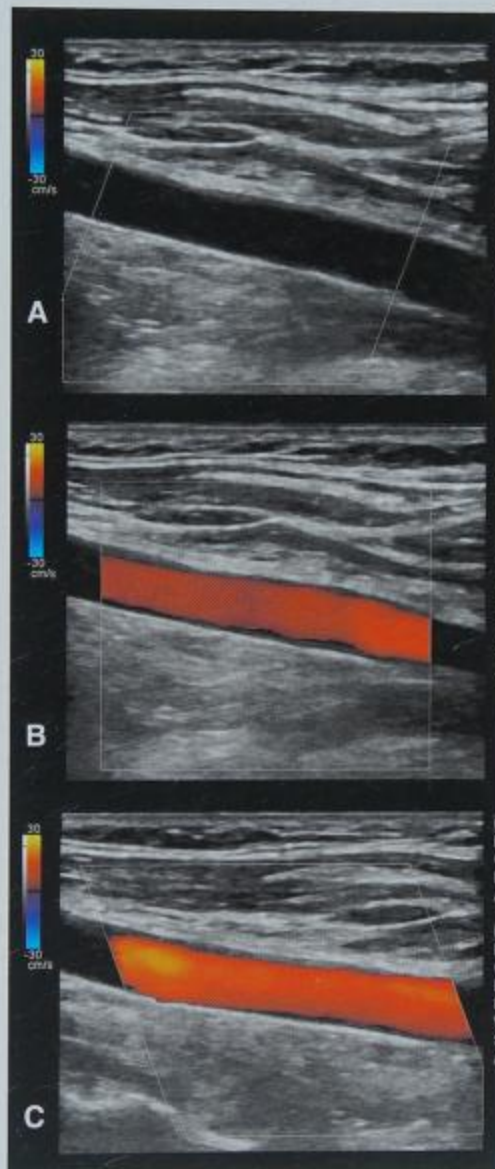


**Fig. 20.4** Three color Doppler images of the same vessel. In a slanted vessel, color still cannot appear when the angle between the direction of flow and sound is 90 degrees.

## Color Doppler Gain

Fig. 20.3 shows three images of the same carotid artery. Compared to images B and C, image A is of high quality and diagnostic value.

**What single control on an ultrasound system can make color appear throughout the color box as shown in image B?**

Image B was created by setting the color gain to a level that is too high. When the color gain is set to an inappropriately high level, color appears throughout the color box. A term that effectively describes this is **color confetti**.

**What single control on an ultrasound system can make color disappear as shown in image C?**

The color gain is set too low in image C and all color has disappeared. It is important to distinguish the absence of color from low color gain and its absence because of perpendicular incidence (see Fig. 20.4A).

In Fig. 20.5C, the sound beam and flow directions are not perpendicular to each other. For color to appear in image C, the sonographer can increase the color Doppler gain.

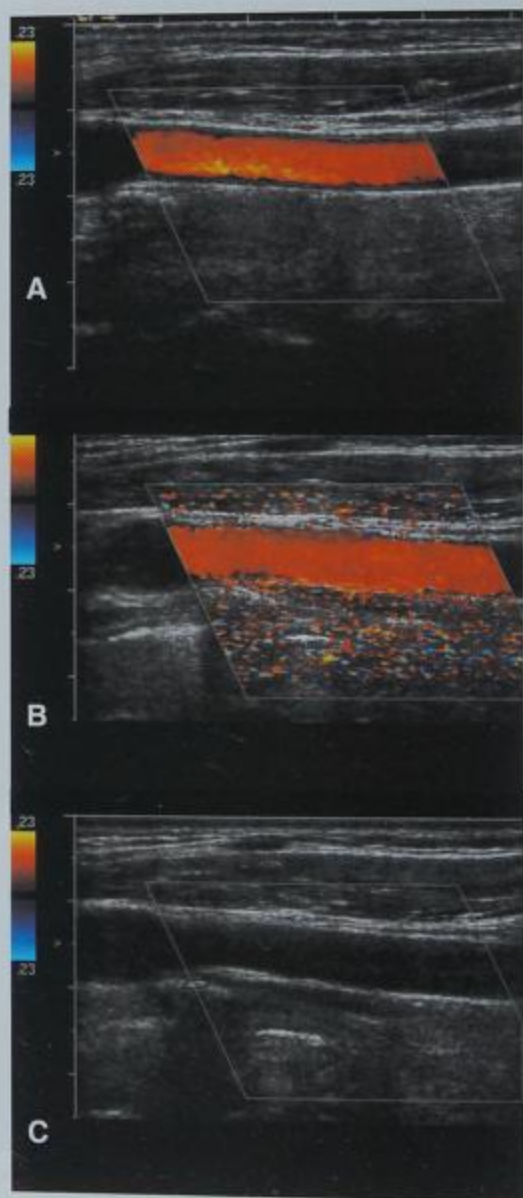


**Fig. 20.5** The amount of color present on a color flow Doppler image can be controlled with the color Doppler gain setting.



Fig. 20.6 shows three images of the same normal kidney. Compared to images B and C, image A is of high quality and diagnostic value.

***What single control on an ultrasound system can create image B?***

The color gain is set too high in image B. When the color gain is set to an inappropriately high level, color appears throughout the color box. A term that describes this effectively is color confetti.

***What single control on an ultrasound system can make color disappear throughout the color sector?***

Image C was created with too low a color gain setting. When the color gain is set to an inappropriately low level, all color will disappear in the image. Since this image is sector shaped, it is unnecessary to consider that the sound beam and flow are perpendicular.

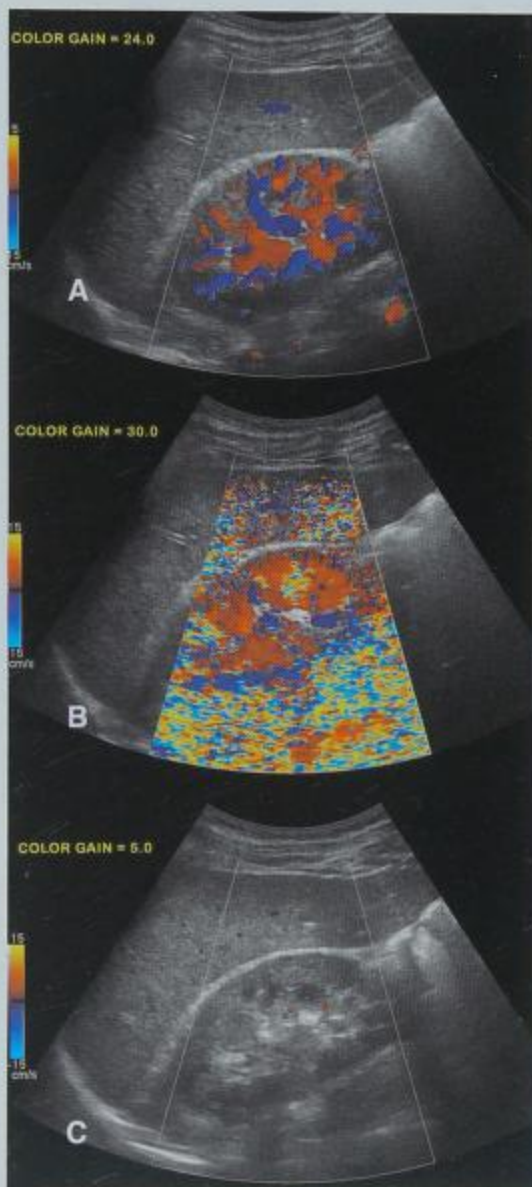


**Fig. 20.6** The amount of color present on a color flow Doppler image can be controlled with the color Doppler gain setting.

## Spectral Doppler Gain

The spectrum in Fig. 20.7A is high quality.

***What alteration was responsible for the change in the appearance of the spectrum from image A to image B?***

Image B was created by increasing the pulsed Doppler gain to a level that is too high. Gray scale noise appears throughout the spectrum when the pulsed Doppler gain is set too high.

***What alteration was responsible for the change in the appearance of the spectrum from image A to image C?***

Image C was created by decreasing the pulsed Doppler gain to a level that is too low. When the pulsed Doppler gain is set to an inappropriately low level, all gray scale will disappear in the image. Not only does the noise vanish, so does the meaningful Doppler spectrum.

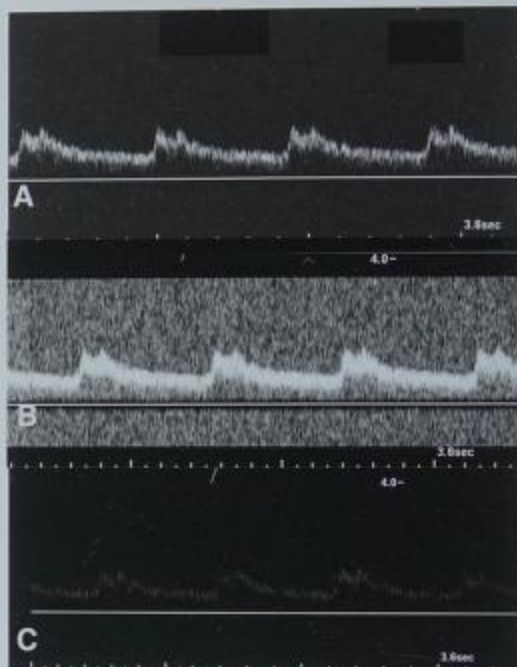


**Fig. 20.7** Pulsed Doppler gain settings alter the gray scale content of a spectral display.

## Aliasing

*What artifact appears in image A in Fig. 20.8?*

Aliasing is present in the color Doppler image in image A.

Image B is a zoomed image of the flow in the artery (upper vessel). The central flow stream is blue, indicating flow toward the transducer, or from right to left (blue arrow).

The flow streams closer to the vessel walls are red, indicating flow away from the transducer, or from left to right (red arrow). It is unlikely that there is flow in different directions within a single vessel. Aliasing should be considered as a possible source of this peculiar color variation, whenever the color changes directly from red to blue or vice versa.

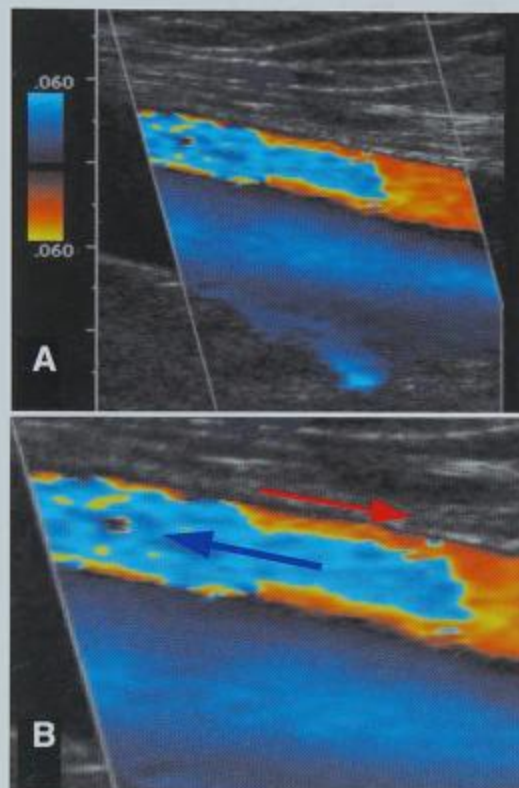


**Fig. 20.8** Aliasing in a color flow Doppler image.



## Flow Reversal vs. Aliasing

*How can we distinguish bidirectional flow from aliasing with color flow Doppler?*

Bidirectional flow and aliasing appear differently. The color map holds the key. Two identical color maps are displayed in Fig. 20.9. On map A, an arrow passes through the center of the map. When using this color map, flow reversal is present in a vessel when the colors red, black, and blue are next to each other.

On map B, an arrow passes from the very top around the outside to the very bottom of the map. When using this color map, aliasing is present on the image when light blue and green are adjacent.

In other words, if the colors that touch each other in the image go through the map's middle, flow reversal is present (image A). If the colors that touch each other go around the outside of the map, aliasing is present (image B).

*Is the blue area in this image aliasing or flow reversal?*

To answer this question, look at the colors that are adjacent to the blue area in Fig. 20.10. The transition of colors is from red to black to blue (yellow arrow). On the map, red to black to blue forces us to move through the center of the map. This color transition indicates flow reversal.

Aliasing on the image would appear as green adjacent to yellow.

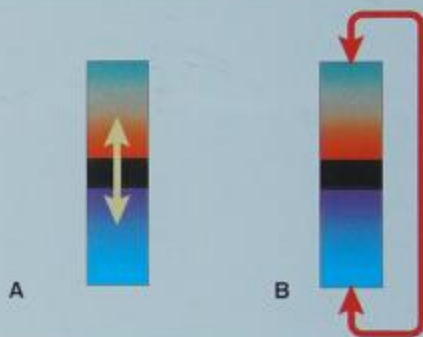


**Fig. 20.9** If the colors that touch each other go through the map's middle, flow reversal is present (A). If the colors that touch each other go around the outside of the map, aliasing is present (B).

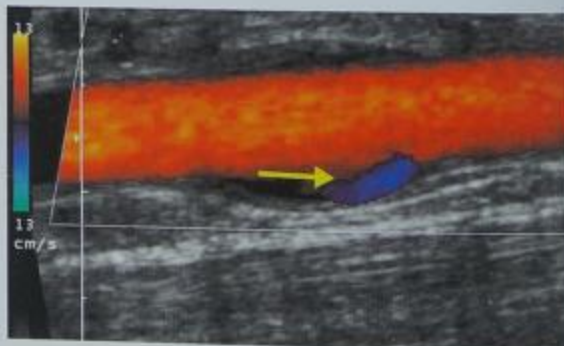


**Fig. 20.10** Flow reversal in a color Doppler image.

### *How is aliasing reduced or eliminated on a color Doppler image?*

Five techniques for eliminating aliasing appear on page 319. Some of these techniques are not applicable to color flow Doppler. For example, using continuous wave Doppler is not reasonable within the context of color Doppler.

The most effective way to eliminate aliasing on a color flow image is to increase the velocity scale. Aliasing is eliminated in Fig. 20.11B, where the scale is 0.55 m/s as compared to image A, where the scale is 0.07 m/s.

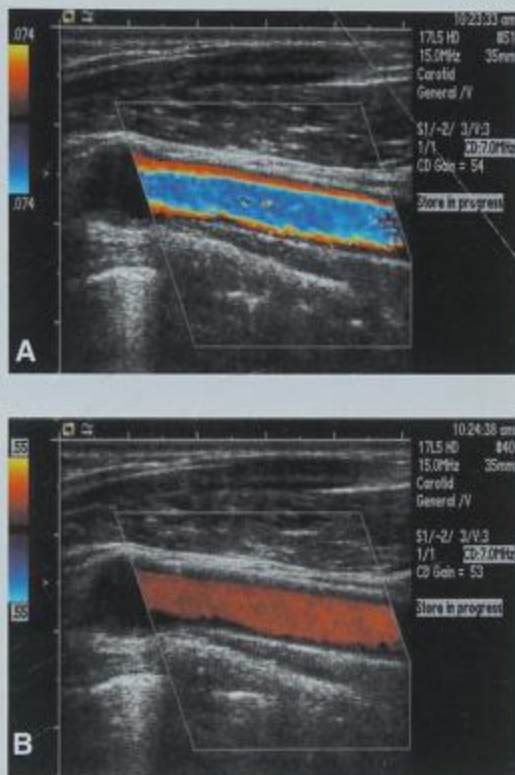


**Fig. 20.11** Increasing the scale of a color Doppler image can eliminate aliasing.

***Does increasing the scale have any other effect on a color Doppler image?***

Yes. Increasing the color Doppler scale **decreases the sensitivity** to slow flows.

Aliasing is present in the upper vessel of Fig. 20.12A. This vessel is an artery and the velocity is high. The lower vessel is a vein, where the velocity is low.

The scale is increased in Fig. 20.12B. As a result, aliasing no longer appears in the artery. Increasing the scale is an effective way to eliminate aliasing.

Color is now absent in the vein because the Doppler is insensitive to slow flows at this scale setting. Low velocities are lost.

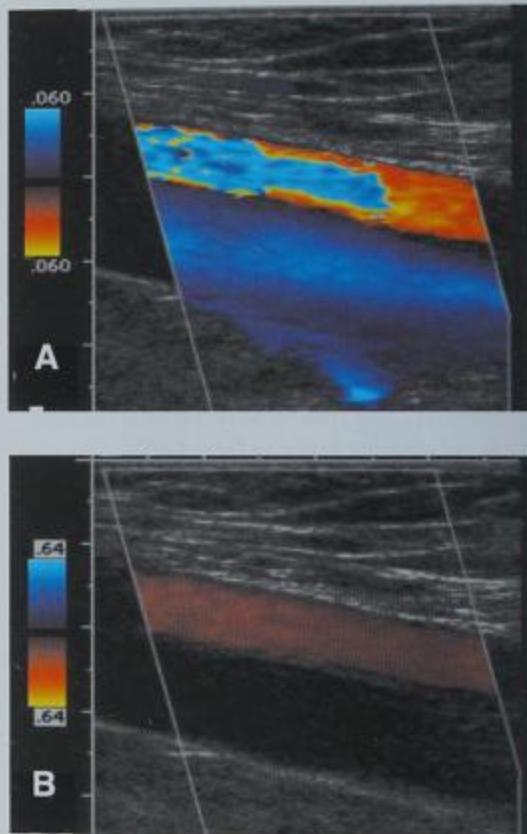


**Fig. 20.12** Low velocity scale, image A. High velocity scale, image B. Increasing the scale of a color Doppler image can eliminate aliasing. Sensitivity to low flows is reduced.



## Wall Filter

Image A in Fig. 20.13 displays an adjacent pair of vessels. The artery appears in red and the vein appears in blue.

***What adjustment did the sonographer perform to create image B?***

The sonographer increased the wall filter to a very high level. Two changes appear when comparing images A and B. First, the color in the vein has vanished. Second, the ghosting artifact along the deeper wall of the artery (yellow arrow, image A) has also disappeared. Color in the artery is limited to the lumen and no longer extends deeper than the vessel wall.

A description of the wall filter appears on page 334. The wall filter selectively eliminates low frequency Doppler shifts.

The application of a wall filter to image A resulted in the removal of color from the slowly moving blood cells in the vein and the slowly moving tissue. Note that the wall filter leaves the high velocity flows unchanged.

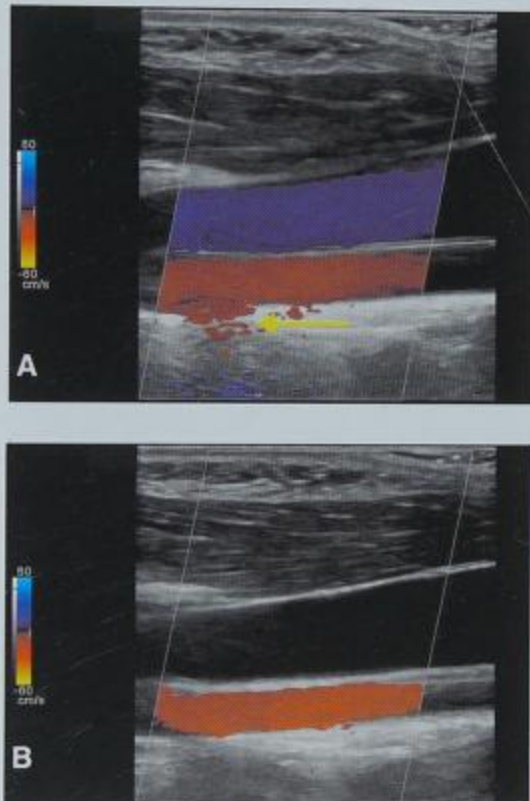


**Fig. 20.13** The wall filter removes the color from slowly moving reflectors such as blood cells and vibrating tissues.

**What adjustment did the sonographer perform to change the upper spectrum (image A) into the lower spectrum (image B) in Fig. 20.14?**

The sonographer increased the wall filter to a higher level. Wall filters are used in both color flow and spectral Doppler. In image A, Doppler shifts close to the baseline are displayed. In image B, small Doppler shifts close to the baseline no longer appear.

In image B, small Doppler shifts close to the baseline no longer appear.

Just like color flow, the wall filter selectively eliminates low frequency Doppler shifts near the baseline. Note that the wall filter does not affect the appearance of higher velocity flows.



**Fig. 20.14** Wall filters eliminate low velocity flows near the baseline of a Doppler spectrum.

Fig. 20.15A displays a cross-sectional, or transverse, view of an adjacent pair of vessels. The artery is the smaller, multicolored vessel. The vein, which is larger, appears in blue.

***What adjustment did the sonographer perform to create the image B?***

The sonographer increased the wall filter to a higher level. The color in the vein has vanished. The wall filter selectively eliminates low frequency Doppler shifts. Small Doppler shifts are created by slowly moving structures such as venous blood flow.

Note that the wall filter does not alter the appearance of higher velocity flows present within the lumen of the artery.

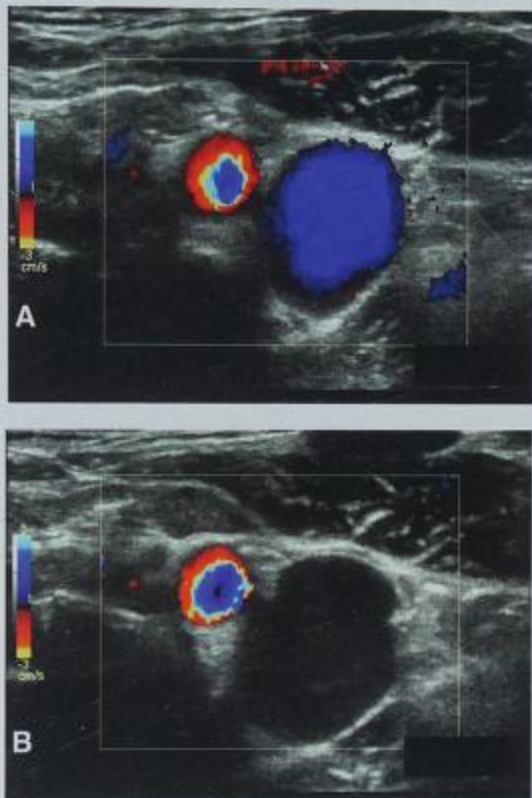


**Fig. 20.15** Transverse view of an artery and a vein; without wall filter in image A and with wall filter in image B.



## Wall Filter vs. Increasing Scale

Fig. 20.16 displays an adjacent pair of vessels. The lower vessel is an artery and the upper vessel, colored blue, is a vein. The color within the vein has vanished in image B.

***What adjustment did the sonographer perform to create image B?***

The sonographer increased the scale. In image A, aliasing appears in the artery. The appearance of adjacent colors, red, yellow, light blue, and dark blue, is evidence of aliasing. In image B, aliasing is no longer present in the artery. This is consistent with increasing the scale.

The vein no longer appears blue because as the scale increases, sensitivity to slow flow is reduced. Slow flows are assigned the black color in the center of the color map.

It is reasonable to suggest that the blue color in the vein was removed by increasing the wall filter. Although reasonable, this suggestion is not supported by the change in arterial flow. A wall filter will alter low velocity flows, while leaving high velocity flows unchanged.

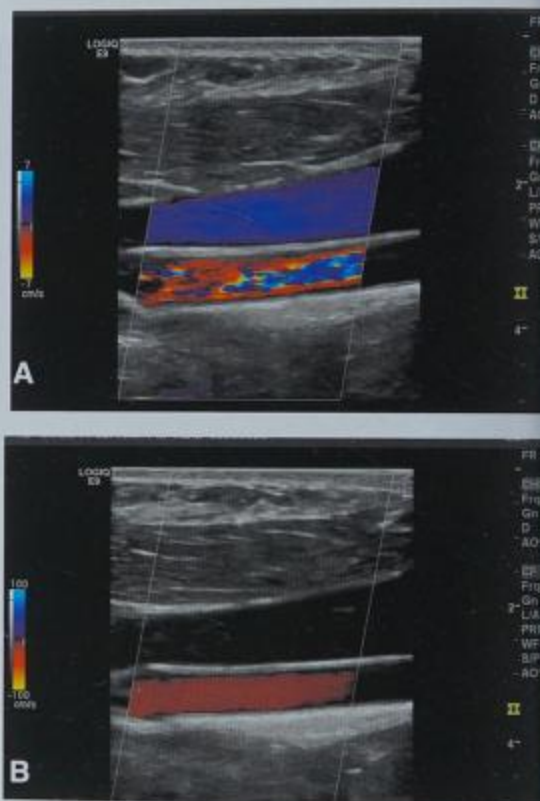


**Fig. 20.16** Low velocity scale, image A. High velocity scale, image B. Increasing the velocity scale eliminates aliasing and removes color from low velocities on the image.

## Artifacts

In its broadest sense, an **artifact** is essentially an error in imaging. This chapter discusses how an ideal image is formed, and describes the characteristic features of artifacts.

### Types of Artifacts

Artifacts include reflections that are described as:

- not real
- not seen on the image
- incorrect shape or size
- incorrect position
- incorrect brightness

### Causes of Artifacts

Artifacts result from:

- violation of assumptions
- equipment malfunction or poor design
- the physics of ultrasound
- operator error

## Image Characteristics

Several terms are used to describe ultrasonic image features:

### Hyperechoic

Portions of an image that are brighter than surrounding tissues, or tissues that appear brighter than normal.

### Hypoechoic

Portions of an image that are not as bright as surrounding tissues, or tissues that appear less bright than normal.

### Anechoic

An extreme form of hypoechoic, meaning entirely without echoes (echo-free).

### Isoechoic

Describes structures with equal echo brightness.

### Homogeneous

A portion of tissue or an image that has similar echo characteristics throughout.

### Heterogeneous

A portion of tissue or an image that has differing echo characteristics throughout.

## Basic Assumptions Used in Imaging Systems

Six assumptions are incorporated into the design of every ultrasound system. Artifacts appear when these assumptions are not true. Most artifacts are explained by identifying which assumptions were violated during image creation.

### Six Assumptions of Imaging Systems

1. Sound travels in a straight line.
2. Sound travels directly to a reflector and back.
3. Sound travels in soft tissue at exactly 1,540 m/s.
4. Reflections arise only from structures positioned in the beam's main axis.
5. The imaging plane is very thin.
6. The strength of a reflection is related to the characteristics of the tissue creating the reflection.

Artifacts appear in some views and disappear in others, whereas actual anatomy always remains visible. When corrective measures are taken, artifacts often vanish.

Instrument malfunction should be considered when obvious artifacts remain visible even after corrective measures have been taken. Contact a service engineer to resolve suspected instrumentation problems.



## Reverberation

Reverberations appear on the display as **multiple, equally spaced echoes** caused by the bouncing of the sound wave between two strong reflectors positioned **parallel to the ultrasound beam** (see Fig. 21.1 and Fig. 21.2).

Assumption #2 on page 356, sound travels directly to a reflector and back, is invalid.

### Characteristics of Reverberation

#### Reverberations

- appear in multiples.
- appear equally spaced.
- are located parallel to the sound beam's main axis.
- are located at ever-increasing depths.

Reverberation artifact places too many reflections on the image. The first and second reflections, closest to the transducer, are real, but the remaining echoes (which appear deeper) do not correctly correspond to true anatomic structures.

**Note:** Reverberations resemble a ladder or Venetian blind.

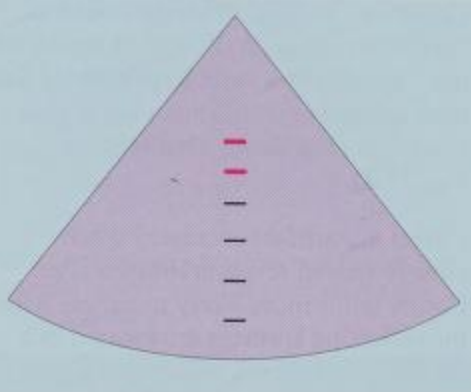


**Fig. 21.1** Reverberations are created when a sound wave bounces back and forth between two strong reflectors. The first two reflections (red) are real, the others (black) are artifacts.

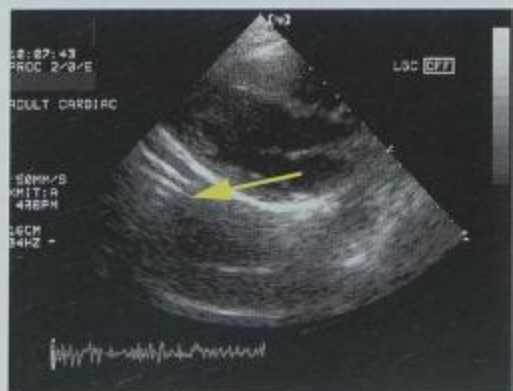


**Fig. 21.2** Reverberations (yellow arrow) are multiple, equally spaced reflections.

## Comet Tail

Comet tail artifact, often described as “reverberation with the spaces squeezed out,” appears as a **solid hyperechoic line** directed downward. Comet tail is also known as **ring down artifact** (see Fig. 21.3).

Comet tail artifact is created when closely spaced reverberations merge. Comet tail is more likely to appear when the reflecting surfaces are located in a medium with a very high propagation speed, such as a mechanical heart valve (see Fig. 21.4).

Comet tail can also arise from the resonance, or vibration, of small structures such as gas bubbles after they have been bombarded by a sound pulse.

Assumption #2 on page 356, sound travels directly to a reflector and back, is invalid.

### Characteristics of Comet Tail

Comet tail

- appears as a single long hyperechoic echo.
- is located parallel to the sound beam's main axis.

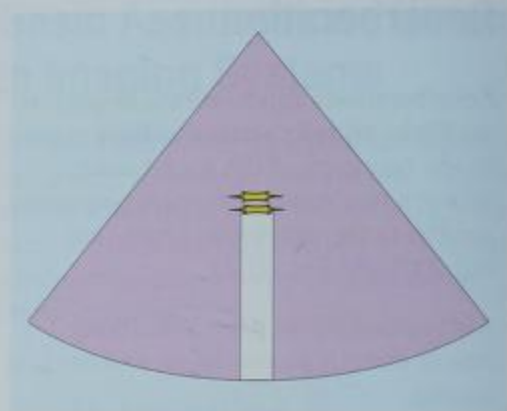


**Fig. 21.3** Comet tail artifact appears when a sound wave bounces back and forth between two very closely spaced objects.

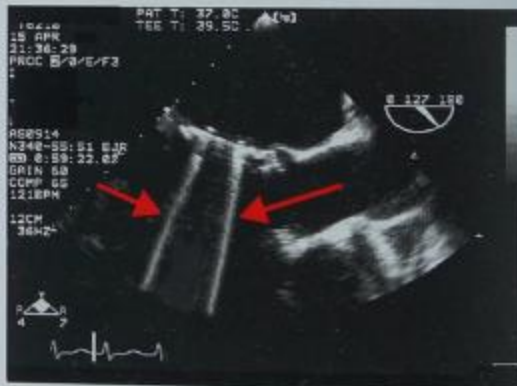


**Fig. 21.4** Two comet tail artifacts are created by leaflets of a prosthetic heart valve because sound waves travel fast in the leaflets and the reflecting boundaries are close together.

## Shadow

Shadowing appears as a **hypoechoic** or **anechoic** region extending downward from a highly attenuating structure. Shadows are the same color as the image background (see Fig. 21.5).

When too much attenuation occurs, deep reflecting surfaces do not appear on the image; thus, shadowing prevents the display of true anatomic structures (see Fig. 21.6 and Fig. 21.7).

Shadows appear when the **attenuation is higher** in the tissue above the shadow than in the surrounding tissue.

Assumption #6 on page 356, the intensity of a reflection is related to the tissue creating the reflection, is invalid.

### Characteristics of Shadowing

- Hypo- or anechoic (background color).
- The result of too much attenuation.
- Located beneath the structure with abnormally high attenuation.
- Prevents visualization of true anatomy on the scan.

**Note:** Shadows may provide valuable diagnostic information that helps to characterize tissue.

Shadowing is entirely **unrelated** to the speed of sound in a medium.

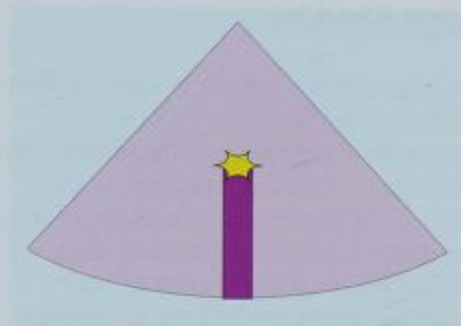


**Fig. 21.5** Shadows are hypoechoic regions that extend beneath structures with abnormally high attenuation.



**Fig. 21.6** A shadow created by the mandible of a fetus.



**Fig. 21.7** A shadow created by a gallstone.



## Edge Shadow

An edge shadow artifact is a special form of shadowing that appears as a **hypoechoic region** extending down from the edge of a curved reflector. Since hypoechoic regions are the same color as the image background, edge shadow artifact prevents the display of true anatomic structures that are positioned within the extended hypoechoic region.

With edge shadow, the sound beam refracts (transmits with a bend) at the edge of a curved reflector. The beam simultaneously diverges, resulting in a drop in intensity. This **decrease in intensity** causes edge shadowing (see Fig. 21.8, Fig. 21.9, and Fig. 21.10).

An edge shadow is also called **shadowing by refraction**.

Assumption #6 on page 356, the intensity of a reflection is related to the characteristics of the tissue creating the reflection, is invalid.

## Characteristics

- Hypo- or anechoic (background color).
- Results when the beam spreads after striking a curved reflector.
- Extends downward from the curved reflector's edge, parallel to the beam.
- Prevents visualization of true anatomy on the scan.

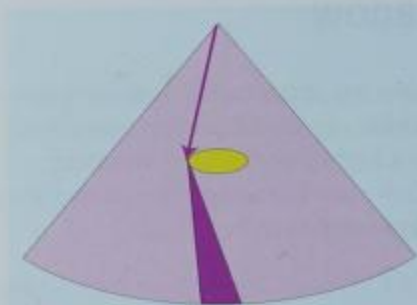


**Fig. 21.8** Edge shadows are created as sound beams refract and diverge along the edge of a curved structure.

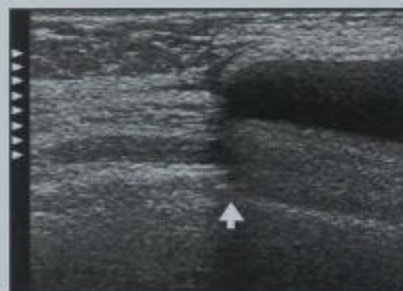


**Fig. 21.9** Edge shadow created at the curved border of a breast implant.



**Fig. 21.10** Edge shadow created along the curved border of a testicle.

## Enhancement

Enhancement artifact appears as a **hyperechoic** region beneath tissues with **abnormally low attenuation** (see Fig. 21.11). Hyperechoic regions are brighter and the same color as the foreground (or echoes) of the image.

Although the number of reflectors on the image is correct, some of them are overly bright (see Fig. 21.12 and Fig. 21.13).

Assumption #6 on page 356, the intensity of a reflection is related to the characteristics of the tissue, is invalid.

**Hint:** Enhancement artifact is the opposite of shadowing.

**Note:** Enhancement artifact can be clinically useful. It may provide valuable diagnostic information that helps to characterize tissue.

Enhancement artifact is entirely **unrelated to the speed** at which sound travels in a medium.

## Characteristics

- **Hyperechoic** (appears the same as the foreground color).
- The result of too little attenuation.
- Located beneath a structure with abnormally low attenuation.

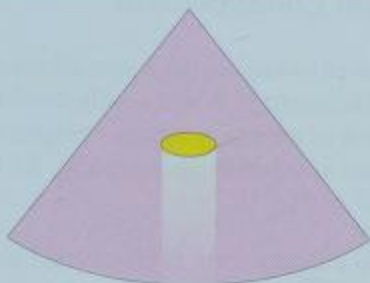


**Fig. 21.11** Enhancement is a hyperechoic region that extends beneath structures with abnormally low attenuation.



**Fig. 21.12** Enhancement (red arrow) created by the cystic structure in breast tissue. The cyst has a lower attenuation rate than surrounding tissues.



**Fig. 21.13** Enhancement artifact created by the gall bladder.

## Focal Enhancement

Focal enhancement is a special form of enhancement in which a **side-to-side region** of an image appears brighter than tissues at other depths (see Fig. 21.14 and Fig. 21.15).

Focal enhancement is also called **focal banding**. Focal banding has the same appearance as an incorrect TGC setting.

Banding is most prominent at the focus. When a beam is strongly focused, the intensity in the focal zone is increased. Reflections from the focal zone may be abnormally strong.

Structures at the focus appear brighter than those at other depths. An entire horizontal region of tissue appears **hyperechoic**.

Assumption #6 on page 356, the intensity of a reflection is related to the characteristics of the tissue, is invalid.

### Characteristics

- A hyperechoic side-to-side region (appears the same as the foreground color).
- Results from increased intensity at the focus.

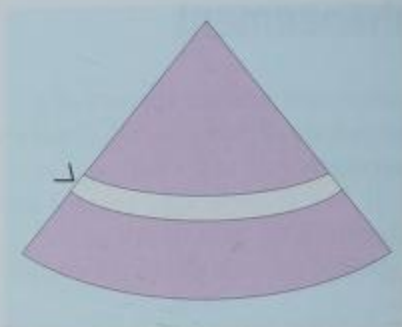


Fig. 21.14 Focal banding is a hyperechoic horizontal region at the depth of the focus.

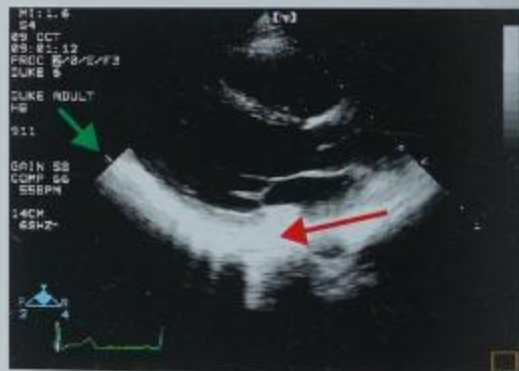


Fig. 21.15 Focal enhancement created by powerful focusing of a sound beam with a phased array transducer (red arrow). Note the location of the focus (green arrow).



## Mirror Image

Mirror image artifact is created when sound reflects off a strong reflector (mirror), and is redirected toward a second structure. This redirection causes a replica, or second copy, of the structure to incorrectly appear on the image (see Fig. 21.16 and Fig. 21.17).

The artifact is located **deeper** than the real structure. The mirror is always located along a straight line between the transducer and the artifact.

In addition to conventional gray scale imaging, mirror image artifact may appear in color Doppler. In Fig. 21.18, the shallower vessel is real, and the deeper vessel is a mirror image artifact.

Assumptions #1, sound travels in a straight line, and #2, sound travels directly to a reflector and back to the transducer, are invalid (see page 356).

## Characteristics of Mirror Image

- A second copy of a true reflector.
- The artifact appears deeper than the true reflector.
- A bright reflector, the mirror, lies on a straight line between the artifact and the transducer.
- True reflector and artifact are equal distances from the mirror.

## Crosstalk

Crosstalk artifact is a **mirror image** artifact that appears on a **spectral Doppler display**. It has been previously described on page 335.

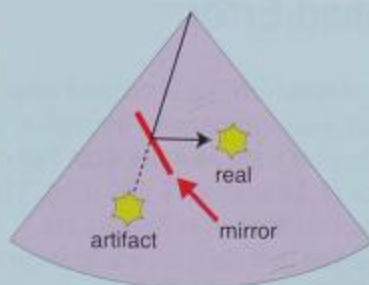
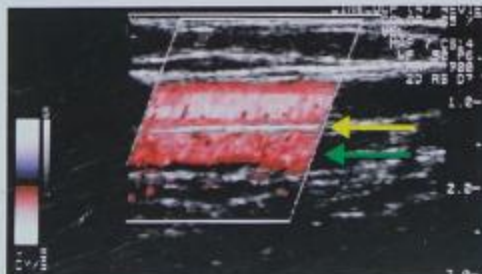


**Fig. 21.16** Mirror image artifact appears as a replica of a true reflector. The artifact is always deeper than the true anatomy.



**Fig. 21.17** Mirror image artifact created in a tissue equivalent phantom. The mirror is the angled line. The artifact is the second copy of the cystic structure. Source: Cindy Rapp.



## Speed Error

Speed error artifact is created when a sound wave propagates through a medium at a speed other than that of soft tissue (1.54 km/s or 1,540 m/s). The correct number of reflectors are displayed, but they appear at incorrect depths. See Fig. 21.19.

Speed errors appear as a step-off, as if structures are “split” or “cut.”

When the medium’s speed is *slower than* that in soft tissue (see Fig. 21.20):

- Sound travels slower than the ultrasound system expects.
- Pulses return from their trip in the body—slow, Slow, SLOW!!
- Go-return time is too long.
- System assumes reflectors are far from transducer.
- Reflectors placed too deep on image.
- Distances are overestimated (reported number is too large).

When the medium’s speed is *faster than* that in soft tissue:

- Sound travels faster than the ultrasound system expects.
- Pulses return from their trip in the body—fast, Fast, FAST!!
- Go-return time is too short.
- System assumes reflectors are close to the transducer.
- Reflectors are located too shallow on image.
- Distances are underestimated (reported number is too small).

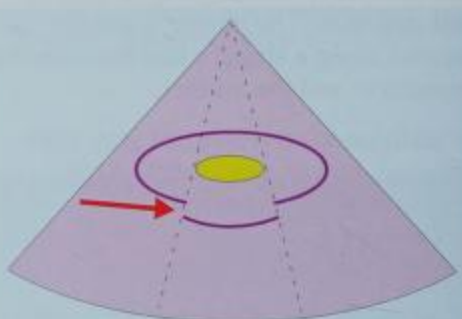


**Fig. 21.19** Speed error artifact. Sound travels in the yellow structure at a speed slower than soft tissue, thereby displacing the reflection beneath it downward (red arrow).



**Fig. 21.20** Speed error artifact created by a silicone breast implant. The step-off displaces tissues below the implant downward, indicating that the speed of sound in the implant is slower than 1.54 km/s.

Propagation speed errors are also called **range error artifact**.

Assumption #3 on page 356, sound travels at a speed of exactly 1,540 meters per second, is invalid.

### **Example**

Question: Two pins in a test object are 100 mm apart. On the display of an ultrasound system, they appear 90 mm apart. How will these two pins appear on the display if they were 50 mm apart in the test object?

Answer: The two pins will appear 45 mm apart: the ultrasound system underestimates true distances by 10%, so 100 mm is displayed as 90 mm. Thus, 50 mm will be underreported by 10% and the pins will appear 45 mm apart on the display.

## **Characteristics of Speed Error**

- Correct number of reflectors.
- Improper depth.
- Appears as a step-off.



## Lobes

Lobe artifact appears when sound energy is transmitted in a direction other than along the beam's main axis.

**Note:** Lobe artifact degrades lateral resolution.

Lobes are weaker than the primary beam and do not typically create reflections that appear on an image. However, a reflection may be created when a strong reflector is in the path of the lobe. The system interprets this reflection as arising from a structure positioned along the beam's main axis.

It is impossible to distinguish the true reflector and the artifact from a single image. However, we can identify the artifact with the use of multiple views. Usually, the real anatomy will appear in all views, whereas the artifact will appear in only a few views.

Assumption <sup>#4</sup> ~~on~~ on page 356, reflections arise from structures located along the beam's main axis, is invalid.

### Characteristics of Lobe Artifact

- A second copy of the true reflector.
- The artifact and the true reflector are located **side by side** at the same depth.

## Side Lobes and Grating Lobes

Lobe artifacts have different names based on the type of transducer that creates them (see Fig. 21.21). Lobes created by a single crystal transducer, such as a mechanical probe, are called **side lobes** (see Fig. 21.22). Lobes created by array transducers are called **grating lobes**.

### Reducing Grating Lobes

Grating lobe artifact can be reduced by dividing each PZT element into small pieces—a process called **subdicing** (see page 193).

Grating lobes can be further reduced by exciting the subdiced elements with different voltage. Elements closer to the center of the sound beam are excited with higher voltages, while the outermost elements, which are farther away from the beam's center, are excited with lower voltages. This process of differential excitation is called **apodization** (see page 193).

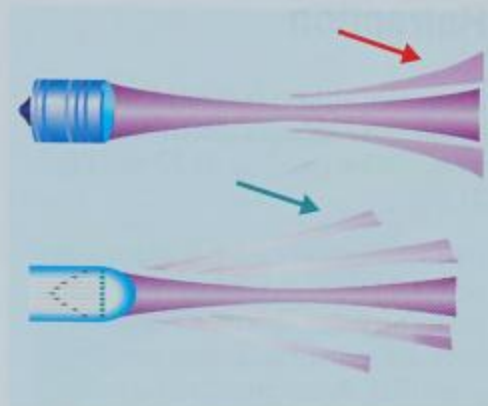


**Fig. 21.21** Side lobes (upper, red arrow) and grating lobes (lower, green arrow) diminish lateral resolution.

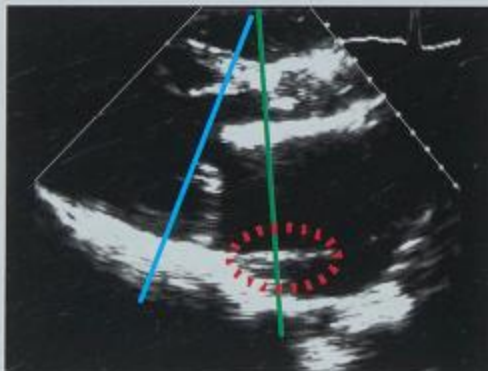


**Fig. 21.22** The linear reflection in the red circle is a side lobe artifact. The main beam is identified by the green line, while the side lobe is blue. A reflection arising from the side lobe is placed along the main beam. The reflection in the red circle does not arise from tissue in that location. It is a side lobe artifact.

**Table 21.1** Methods to Eliminate Lobes

#### Reducing Lobe Artifacts

- subdicing
- apodization

## Refraction

Refraction artifact is created when a sound pulse changes direction during transmission (see Fig. 21.23 and Fig. 21.24).

Refraction occurs when a sound wave strikes a boundary obliquely and the media on either side of the boundary have different propagation speeds (see page 101). Remember: refraction is transmission with a bend.

**Note:** Refraction artifact degrades lateral resolution.

Assumption #1 on page 356, sound travels in a straight line, is invalid.

### Characteristics

- A second copy of the reflector.
- The copy is **side by side**, or at the same depth as the true reflector.

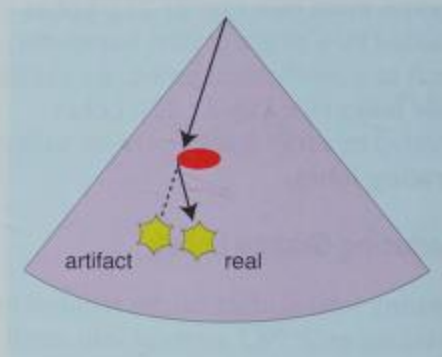


**Fig. 21.23** A second copy of a true reflector incorrectly appears on the image. The artifact is at the same depth as the true reflector.

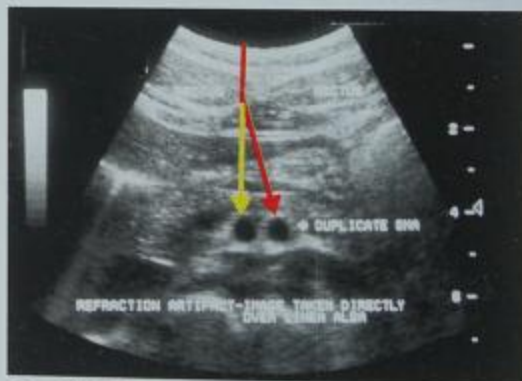


**Fig. 21.24** The second vessel (left) in this image is a refraction artifact. It is impossible to identify this artifact with only one image. Multiple views are required.



## Slice Thickness

With two-dimensional imaging, sonographers may believe that the imaging plane is thin and uniform, similar to a thin slice of cheese. In reality, the imaging plane is three dimensional and is neither thin nor of uniform thickness. The beam flares out like the bell of a trumpet. Therefore, reflections from structures above or below the assumed imaging plane may appear in the image (see Fig. 21.25).

Slice thickness is also called **section thickness artifact** or **partial volume artifact**.

Slice thickness artifact is related to the dimension of the beam that is perpendicular to the imaging plane.

**Elevational resolution** is determined by the thickness of the imaging plane.

The true reflector lies either above or below the assumed imaging plane, but is displayed within the image.

Slice thickness artifact fills in hollow structures such as cysts.

Slice thickness artifact is reduced with thinner imaging planes, such as those created by  $1\frac{1}{2}$ -dimensional array transducers (see page 188).

Assumption #5 on page 356, the imaging plane is extremely thin, is invalid.

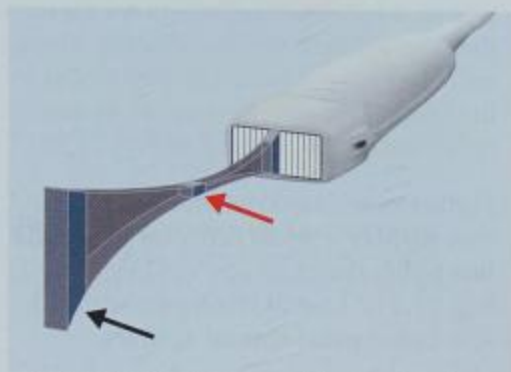


**Fig. 21.25** The thickness of the imaging plane varies. Thicker portions of the slice (black arrow) have inferior elevational resolution when compared to thinner portions (red arrow).

## Lateral Resolution

Lateral resolution artifact occurs when a pair of side-by-side reflectors are closer than the width of the sound beam. These reflectors are positioned perpendicular to the beam. **Two objects appear as one reflection** on the image (see Fig. 21.26).

Furthermore, lateral resolution artifact may **display a small reflector as a wide line** rather than a narrow dot (see Fig. 21.27). Lateral resolution artifact is also called **point spread artifact**.

Lateral resolution artifact is least likely to occur at the focus, where the beam diameter is smallest. It is most likely to occur where the beam is wide.

## Axial Resolution

Axial resolution artifact is created when a long pulse strikes two closely spaced structures, where one is in front of the other. The structures are parallel to the beam's main axis (see Fig. 21.28). Only one reflection will appear on the image if the structures are closer together than one-half the spatial pulse length.

**Note:** Axial resolution artifact creates one reflection on the image from two closely spaced reflectors.

Transducers that create short pulses (higher frequency transducers and less ringing) minimize axial resolution artifact (see page 148).

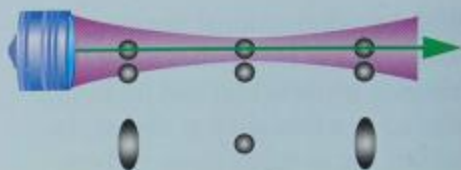


Fig. 21.26 Lateral resolution artifact may create one reflection on the image from two reflectors.



Fig. 21.27 Lateral resolution artifact may create a horizontal reflection from a small reflector.

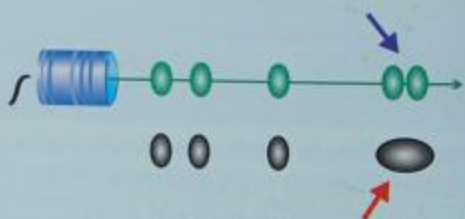


Fig. 21.28 Axial resolution artifact may create one reflection (red arrow) from multiple small reflectors (blue arrow).

## Other Artifacts

### Multipath

Multipath artifact is created when sound pulses glance off a second structure on the way to or from the primary reflector (see Fig. 21.29). As a result, the transmit path length differs from the return path length. Multipath often results in subtle, nonspecific changes that cannot be explicitly identified on the image.

Assumption #2 on page 356, a pulse travels directly to a structure and then back to the transducer, is invalid.

### Curved and Oblique Reflectors

When a sound beam strikes a curved or oblique reflector, some of the reflected sound may be directed away from the transducer (see Fig. 21.30). The amplitude of the reflection received by the transducer may be less than expected. In this case, reflectors:

- are absent on the image
- appear too weak on the image, or
- appear different from other similar reflecting boundaries (see Fig. 21.31).

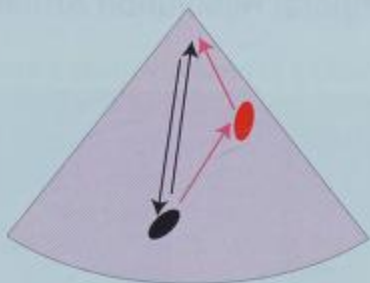


**Fig. 21.29** Multipath artifact appears when some pulses travel directly to and from a reflector (black), while others do not (red).

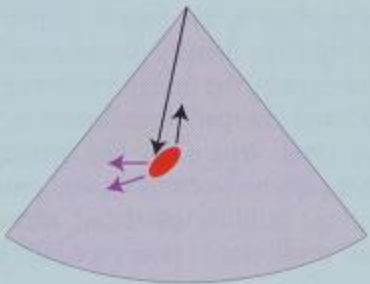


**Fig. 21.30** Curved or oblique reflectors redirect sound waves in directions other than back toward the transducer.



**Fig. 21.31** The structures identified by the three red arrows are anatomically similar. However, they appear with different brightness because the sound waves strike the boundary at different angles.



## Temporal Resolution Artifact

The ability to precisely locate a moving structure at all times is called **temporal resolution**. Temporal resolution is best with high frame rates. Poor temporal resolution, caused by low frame rates, results in less accurate positioning of moving reflectors (see page 198).

## Spatial Resolution Artifact

Spatial resolution is related to the **overall detail** in an image. It is determined by multiple factors, including line density, axial resolution, and lateral resolution. With high line density (closely packed sound pulses), the image exhibits great detail, and the spatial resolution is exceptional. With a low line density (wider gaps between the sound pulses) the image exhibits less detail, and the spatial resolution is poor (see Fig. 21.32).

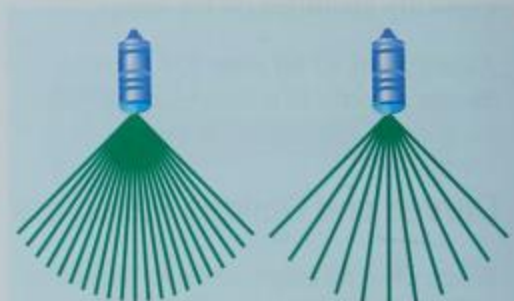


Fig. 21.32 High line density (left) results in better spatial resolution. Low line density (right) degrades spatial resolution.

*How does the system's display affect spatial resolution?*

### Horizontal Lines in a Display

When image information is displayed on a monitor, spatial resolution is affected by the **number of horizontal scan lines per frame**. Spatial resolution is best with a greater number of lines (see Fig. 21.33).



Fig. 21.33 More lines on a monitor (left) provide better spatial resolution (image detail). Fewer lines (right) result in poor spatial resolution.

## Digital Displays

When the image information is in digital form, spatial resolution is related to **pixel density**. Spatial resolution improves with a large number of pixels in an image of fixed size: this is called **high pixel density**. Each pixel is small, resulting in a detailed image with excellent spatial resolution.

With low pixel density, each pixel is large and the spatial resolution degrades. Spatial resolution artifact occurs when the pixel size is greater than the size of the reflector (see Fig. 21.34).



**Fig. 21.34** Higher pixel density (left) results in better spatial resolution, whereas lower pixel density (right) degrades spatial resolution.

## Range Ambiguity Artifact

In sonographic imaging, it is assumed that all reflections are received by the transducer before the next pulse is transmitted. Imagine that a reflection is created by a very deep structure and arrives at the transducer after the next pulse has been transmitted. This very deep reflection will be interpreted as being created by the second pulse and is therefore associated with a very shallow structure. Range ambiguity artifact occurs when a reflecting structure is located deeper than the imaging depth of the image. This reflector is placed at a shallow location on the image.

Range ambiguity artifact is eliminated by increasing the pulse repetition period (PRP). Longer PRP means deeper imaging and decreased pulse repetition frequencies (PRF).

## Noise

**Noise** appears as small amplitude echoes and results from many sources, including electrical interference, signal processing, and spurious reflections (see Fig. 21.35). Noise is more likely to affect low-level hypoechoic regions rather than bright echogenic areas.

## Speckle

Things are not always what they appear to be. It is common to see what appears to be tissue texture, especially within the shallow parts of an ultrasound image. This speckled or grainy appearance is not directly related to the actual biologic tissue. Rather, **acoustic speckle** is noise resulting from the constructive and destructive interference of small sound wavelets. Constructive interference occurs when wavelets are in-phase. Destructive interference occurs with out-of-phase wavelets.

The displayed image will contain fake detail, such as the grainy tissue-like texture previously mentioned. Spatial compounding is an effective tool to reduce speckle.

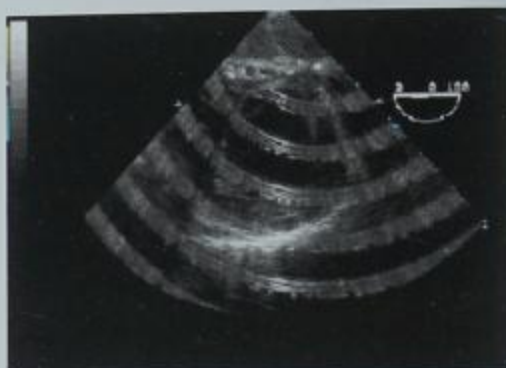


**Fig. 21.35** Electronic interference creates bands of noise on this ultrasound scan.

## Clutter

**Clutter** is another form of noise. Clutter is the presence of false echo signals arising from locations outside of the main sound beam. Side lobes, grating lobes, and section thickness artifact are sources of clutter.

With Doppler, clutter is the contamination of valid Doppler signals with high amplitude reflections from vessel walls or heart muscle. These high amplitude reflections overpower the true Doppler signals created by moving blood.



## Harmonic Imaging

**Harmonic imaging** reduces an image's noise content. The goal of harmonic imaging is to selectively distinguish meaningful reflections from noise, thereby increasing the signal-to-noise ratio (see Chapter 17, *Harmonics and Contrast Agents*).

## Summary

Table 21.2 Artifacts

| Appearance                                                                                             | Possible Cause                                                                                                                                                                           |
|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Anatomic reflectors absent on image                                                                    | <ul style="list-style-type: none"> <li>Shadowing</li> <li>Shadowing by refraction</li> <li>Lateral resolution</li> <li>Axial resolution</li> </ul>                                       |
| Anatomic reflector appears multiple times on image. Artifact positioned deeper than the true anatomy   | <ul style="list-style-type: none"> <li>Comet tail</li> <li>Ring down</li> <li>Reverberations</li> <li>Mirror image</li> </ul>                                                            |
| Anatomic reflector appears multiple times on image. Artifact displaced to the side of the true anatomy | <ul style="list-style-type: none"> <li>Refraction</li> <li>Side lobe</li> <li>Grating lobe</li> </ul>                                                                                    |
| Anatomic reflectors appear with abnormal brightness                                                    | <ul style="list-style-type: none"> <li>Enhancement (hyperechoic)</li> <li>Banding (hyperechoic)</li> <li>Shadowing (hypoechoic)</li> <li>Shadowing by refraction (hypoechoic)</li> </ul> |
| Anatomic structures appear at incorrect depth                                                          | <ul style="list-style-type: none"> <li>Speed errors</li> <li>Range ambiguity artifact</li> </ul>                                                                                         |
| Anatomic structures appear in the incorrect imaging plane                                              | <ul style="list-style-type: none"> <li>Slice or section thickness</li> </ul>                                                                                                             |
| Anatomic structures do not correspond to echoes on the image                                           | <ul style="list-style-type: none"> <li>Acoustic speckle</li> <li>Multipath</li> </ul>                                                                                                    |

## Review: Artifacts

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. When creating an ultrasound image, all of the following assumptions are made <i>except</i>:</p> <ul style="list-style-type: none"><li>A. Sound travels in a straight line.</li><li>B. Sound travels at 1.54 km/s.</li><li>C. The sound beam is extremely thin.</li><li>D. All structures create reflections of equal magnitude.</li></ul>                                                                                                  | <p>1. D. The magnitude of a reflection is related to the scattering strength of the anatomic structure that creates it. For example, reflections from bone are usually strong, whereas reflections from soft tissue are normally weak.</p> |
| <p>2. Which statement regarding axial resolution is incorrect?</p> <ul style="list-style-type: none"><li>A. Axial resolution artifact is related to beam diameter.</li><li>B. Higher quality images are associated with smaller numbers.</li><li>C. Axial resolution may be reported in units of meters.</li><li>D. Numerically, axial resolution equals one-half the pulse length.</li><li>E. Too few reflectors appear on the image.</li></ul> | <p>2. A. Axial resolution is not related to beam diameter. It is related to the length of the pulse.</p>                                                                                                                                   |
| <p>3. An ultrasound pulse has a width of 4 mm, a length of 2 mm, and is produced by a transducer 3,000 times per second. What is the best estimate of the system's axial resolution?</p> <ul style="list-style-type: none"><li>A. 4 mm</li><li>B. 2 mm</li><li>C. 1 mm</li><li>D. 1,500 Hz</li></ul>                                                                                                                                             | <p>3. C. Axial resolution is equal to approximately one-half of the pulse length. The length is 2 mm; therefore, the axial resolution is 1 mm.</p>                                                                                         |

| Questions                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>4. Which of the following statements is true about lateral resolution?</p> <p>A. It is also called angular, transverse, and depth resolution.</p> <p>B. It is reported in units of time.</p> <p>C. It is the same at all depths.</p> <p>D. It can be improved by focusing.</p> | <p>4. D. Lateral resolution, measured in millimeters, depends upon the width of the ultrasound pulse. Focusing narrows the beam width, thereby improving lateral resolution. Choice A is incorrect because depth resolution is not synonymous with lateral resolution.</p> |
| <p>5. All of the following artifacts result in the placement of too many echoes on the image <i>except</i>:</p> <p>A. shadowing</p> <p>B. reverberation</p> <p>C. mirror image</p> <p>D. grating lobes</p>                                                                        | <p>5. A. Shadowing artifact is the incorrect absence of reflectors on the image when a sound pulse is attenuated.</p>                                                                                                                                                      |
| <p>6. Which of the following determines the spatial resolution of a display?</p> <p>A. number of pixels</p> <p>B. number of lines on the display</p> <p>C. number of bits per pixel</p> <p>D. spatial pulse length</p>                                                            | <p>6. B. Spatial resolution is determined by the number of horizontal lines on the display.</p>                                                                                                                                                                            |
| <p>7. Which of the following determines the spatial resolution of a digital display?</p> <p>A. pixel density</p> <p>B. number of lines on the display</p> <p>C. number of bits per pixel</p> <p>D. spatial pulse length</p>                                                       | <p>7. A. With digital displays, spatial resolution is determined by the pixel density.</p>                                                                                                                                                                                 |
| <p>8. Which artifact produces an image with an incorrect number of reflectors?</p> <p>A. propagation speed error</p> <p>B. multipath</p> <p>C. enhancement</p> <p>D. side lobes</p>                                                                                               | <p>8. D. Side lobe artifact places a second echo on an image from a single structure. The other choices create images with the correct number of echoes.</p>                                                                                                               |
| <p>9. True or False. Mirror image artifacts always appear deeper than the true anatomy.</p>                                                                                                                                                                                       | <p>9. True. All mirror image artifacts appear deeper than the actual anatomy.</p>                                                                                                                                                                                          |



| Questions                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>10. Which artifact is unrelated to the dimensions of an ultrasound pulse?</p> <p>A. lateral resolution<br/>B. depth resolution<br/>C. slice thickness<br/>D. refraction</p>                                                                                                                                                                   | <p>10. D. Refraction artifact is not related to the shape of a sound pulse. Refraction artifact depends upon a sound wave striking a boundary with oblique incidence. The propagation speeds of the tissues on either side of the boundary must be dissimilar.</p> |
| <p>11. True or False. It is common to visualize artifacts when the dimension of the sound beam is larger than the reflector's dimension.</p>                                                                                                                                                                                                     | <p>11. True. This is an important concept. Artifacts are likely to occur when the beam is larger than the reflector in the body.</p>                                                                                                                               |
| <p>12. Two reflections, one true and one artifact, are displayed on an ultrasound image. In the body, only one anatomic structure is present. The correct reflection and the artifact are found side by side. What is the most likely cause of this artifact?</p> <p>A. mirror image<br/>B. grating lobe<br/>C. enhancement<br/>D. multipath</p> | <p>12. B. Grating lobe artifact creates a second copy of an anatomic reflector that is positioned alongside the true reflection.</p>                                                                                                                               |
| <p>13. Two distinct reflections are observed on an image, but they actually arise from a single anatomic structure. The artifact is positioned deeper than the correct reflection. What is the most likely cause of this artifact?</p> <p>A. grating lobe<br/>B. side lobe<br/>C. refraction<br/>D. mirror image</p>                             | <p>13. D. A mirror image artifact is positioned deeper than the structure that created it. The other choices generally create artifacts that are located at the same depth as the true reflector.</p>                                                              |
| <p>14. Which one of these artifacts does not result from multiple reflections?</p> <p>A. comet tail<br/>B. reverberations<br/>C. ring down<br/>D. enhancement</p>                                                                                                                                                                                | <p>14. D. Enhancement is an artifact related to abnormal brightness. All the other choices are artifacts associated with multiple reflections.</p>                                                                                                                 |

## Quality Assurance

It is important to validate the consistency of ultrasound images and the accuracy of measurement devices. A quality assurance program is an essential part of every ultrasound laboratory.

### Quality Assurance

Quality assurance is the routine, periodic evaluation of an ultrasound system to guarantee optimal image quality.

Although the appropriate time interval between evaluations depends on the clinical circumstances, quality assurance evaluations must be performed **periodically** and **routinely**.

Quality assurance is a medical and legal necessity for every laboratory. The sonographer is responsible for implementing a quality assurance action plan.

## Requirements

Four requirements for a quality assurance program are:

- assessment of system components
- repairs
- preventive maintenance
- record keeping

## Goals

The five goals of a quality assurance program are:

- guarantee proper operation of the system
- detect gradual changes
- minimize downtime
- reduce the number of non-diagnostic exams
- reduce the number of repeat scans

## Devices

Several devices enable the sonographer to perform quality assurance. Three of these devices are discussed:

1. tissue equivalent phantom
2. Doppler phantom
3. beam profile/slice thickness phantom

## Methods

Proper methods for quality assurance programs are:

- test under known, defined conditions
- use constant instrument settings
- use a phantom with measurable characteristics
- image in an identical environment



## Objective vs. Subjective Standards

An objective statement is completely unbiased. It is not affected by an individual's previous experience, preference, or taste. Objective information is factual, repeatable, and able to be counted. Objective information is the same, even when obtained from different people.

A subjective statement is one that is influenced by an individual's experience or beliefs. Although often based in reality, a subjective statement is colored by a person's perspective or view of reality. Often, it cannot be verified using concrete facts and figures. Subjective information is affected by opinion, belief, or assumption and frequently varies from person to person.

Quality assurance programs should be based on objective standards. The performance of ultrasound systems must be based on measurements and free from personal or biased perceptions.

## Tissue Equivalent Phantom

Tissue equivalent phantoms have ultrasonic features similar to soft tissue. They are used to evaluate characteristics such as gray scale and tissue texture, and multi-focus and adjustable-focus phased array transducers (see Fig. 22.1 and Fig. 22.3).

Tissue equivalent phantoms are similar to soft tissue in the following ways:

- speed of sound (1,540 m/s)
- attenuation
- scattering characteristics
- echogenicity

**Gray scale** is evaluated with this phantom since it contains small scatterers that act like soft tissue. Structures that mimic hollow cysts (hypoechoic) and solid masses (hyperechoic) are also embedded in the phantom (see Fig. 22.2).



Fig. 22.2 Varying gray scale using a tissue equivalent phantom.

Nylon strings may be embedded in the phantom to produce reflections at strategic locations.



Fig. 22.1 Tissue equivalent phantom.

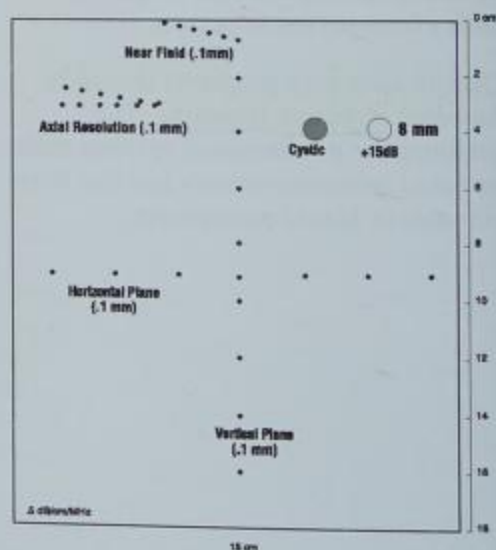


Fig. 22.3 Diagram of a tissue equivalent phantom.

## Doppler Phantom

Flow phantoms are the devices of choice for evaluating Doppler systems. Modern Doppler phantoms include a circulation pump which propels fluid through vessels embedded in a tissue equivalent phantom (see Fig. 22.4).

Other Doppler phantoms contain vibrating strings or moving belts (see Fig. 22.5).

Table 22.1 Doppler Phantoms

| Doppler Phantoms   |
|--------------------|
| • vibrating string |
| • moving belt      |
| • flow phantom     |

Doppler phantoms assess the characteristics of all Doppler modalities, including pulsed, continuous wave, color, and power mode (see Fig. 22.6).



Fig. 22.4 Doppler flow phantom.



Fig. 22.5 Vibrating string phantom.

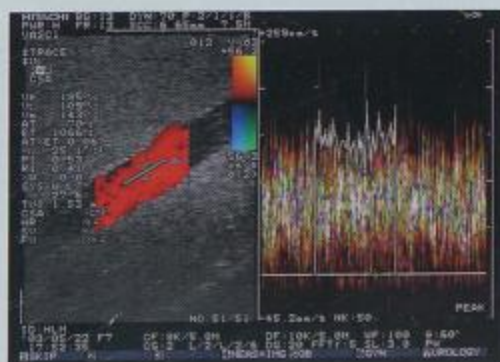


Fig. 22.6 Color and pulsed Doppler ultrasound scan using a flow phantom.



## Slice Thickness Phantom

Another special phantom assesses the slice thickness and its effect upon image accuracy. Slice thickness determines **elevational resolution** (see Fig. 22.7).

Slice thickness is most likely to degrade image quality because the imaging plane is thicker than either the beam width (which determines lateral resolution) or the pulse length (which determines axial resolution).

The commercially available beam profile/slice thickness phantom contains a diffuse scattering plane that is at an angle to the incident sound beam (see Fig. 22.8). The phantom's medium mimics soft tissue. Other, more traditional test objects cannot measure slice thickness.

Slice thickness measures the beam geometry perpendicular to the imaging plane. Thicker slices diminish spatial resolution (image detail) and reduce the ability to visualize small, low contrast reflectors. When the ultrasound beam is overly thick, cystic structures may appear filled in (see page 188).



Fig. 22.7 Slice thickness phantom.

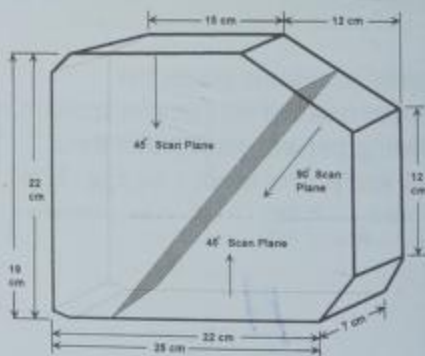


Fig. 22.8 Schematic of a slice thickness phantom.

# Performance Measurements

## Sensitivity

Sensitivity refers to the ability of a system to display low-level echoes. It is evaluated in a variety of ways. Two forms of sensitivity are:

1. normal
2. maximum

### 1. Normal Sensitivity

Normal sensitivity settings are those at which **all the pins, solid masses, and cystic structures** in the test phantom are accurately displayed. Output power, TGC, and amplification are adjusted to establish normal sensitivity.

All subsequent quality assurance and performance measurements are made at the normal sensitivity. Normal sensitivity settings should not vary from one routine evaluation to the next.

Minimum  
- TGC is flat  
- inc. gain from min up to

### 2. Maximum Sensitivity

Maximum sensitivity is evaluated with the output power and amplification of the system set to the maximum practical levels. With these settings, a tissue equivalent phantom is imaged, and the depth of tissue-like texture on the display is measured. Maximum visualization depth is used to assess sensitivity, and should not differ from one routine evaluation to the next.

**Hint:** Sensitivity is also assessed when the sonographer adjusts the system controls to change echo brightness from barely visible to full brightness (saturation).





## Registration Accuracy

Registration accuracy is the ability of the system to place reflections in proper positions while imaging from different orientations.

### Range Accuracy

Range accuracy, or **vertical depth calibration**, describes the system's accuracy in placing reflectors at correct depths located parallel to the sound beam.

If differences appear between the ultrasound scan and the actual pin locations in the test object, the error may be caused by:

- system malfunction, or
- the speed of sound in the phantom is different than 1,540 m/s

**Hint:** The accuracy of reflector depth positioning in A-mode, M-mode, B-mode, and 2-D imaging is called **depth calibration**.

### Horizontal Calibration

Horizontal calibration is the system's ability to place echoes in their correct position when the reflectors are perpendicular to the sound beam.

### Distance Measurement Accuracy

Components of the ultrasound system used to measure distances also require periodic evaluation.

Digital calipers should be checked in both the vertical and horizontal directions.

## Focal Zone

The focus is the depth at which the intensity is the highest and the beam is the narrowest; the **focal zone** surrounds the focus. Lateral resolution is excellent in the focal zone because the beam is narrow. The focus of phased array transducers, which have sonographer-controlled adjustable focusing, must be carefully evaluated. In addition, systems with dynamic receive focusing should produce narrow reflections over a wide range of depths (see page 177).

## Axial Resolution

Axial resolution is the smallest distance at which two pins positioned parallel to the sound beam are displayed as two distinct echoes. Axial resolution is evaluated by scanning sets of successively closer spaced pins within the phantom (see Fig. 22.11, red arrows).

## Lateral Resolution

Lateral resolution is the minimum distance at which two side-by-side pins are displayed as two distinct images (see Fig. 22.12).

Another method to evaluate lateral resolution is to measure the width of reflections on the display that are created by point targets in the phantom. This width approximates the beam diameter at that depth. With traditional transducers, beam diameter varies with depth and is narrowest at the focus.

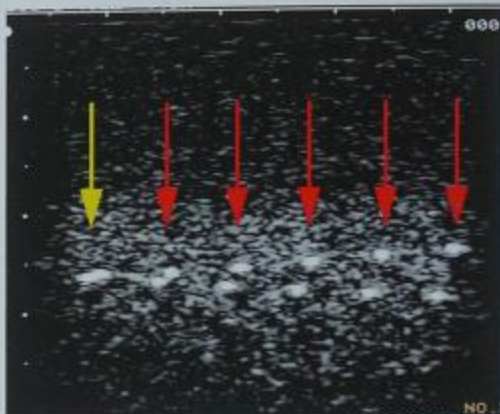


**Fig. 22.11** Axial resolution assessment. The merged reflection identified by the yellow arrow was created by two closely spaced pins parallel to the sound beam's axis.

**Note:** Axial resolution uses pins that are parallel to the sound beam.

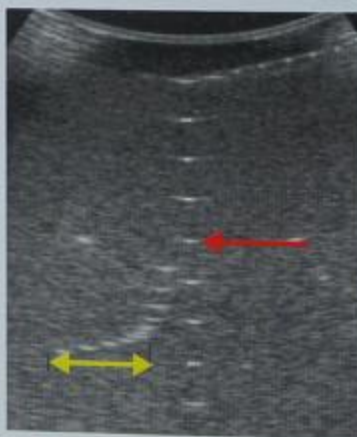


**Fig. 22.12** Lateral resolution assessment. The focus, where the beam is the narrowest, is identified by the red arrow.

## Compensation Operation or Uniformity

Uniformity describes the system's ability to display similar reflectors in the phantom with echoes of equal brightness. With proper TGC, identical reflectors should have the same appearance on the monitor, regardless of their depth.

## Mock Cysts and Solid Masses

The tissue equivalent phantom is used to evaluate the dimension, texture, and fill-in of cysts. The system should accurately display hollow structures as anechoic and solid structures as hyperechoic (see Fig. 22.13).

## Display, Hardcopy Output, and Gray Scale Dynamic Range

Adjusting the system's output power and amplification should produce changes in the gray scale display. It is important to compare the relationship between the image on the system's screen with the output of all other display devices, such as remote viewing stations.

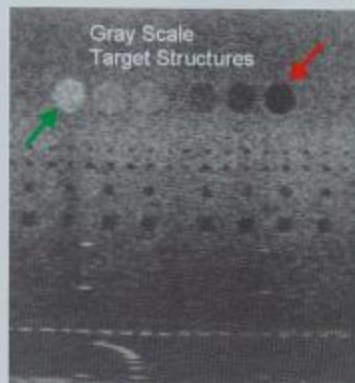


**Fig. 22.13** Assessment of anechoic structures (mock cysts, red arrow) and hyperechoic structures (solid masses, green arrow) using a tissue equivalent phantom.

**Note:** Adjustments to the output power and amplification of the system should alter the appearance of the image on the system's display and all output devices.

Adjustments on a single display device (such as the brightness or contrast of a monitor) alter the image on that particular device only.



## Review: Quality Assurance

| Questions                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. What standard is best used in a quality assurance program?<br>A. subjective<br>B. expert<br>C. objective<br>D. legislative                                                                                                                                                                                   | 1. C, objective. An objective standard is best for a quality assurance program. These standards are free of personal opinion.                                                                                         |
| 2. All of the following are characteristics of a tissue equivalent phantom except:<br>A. speed of sound similar to that in soft tissue<br>B. attenuation properties similar to that of soft tissue<br>C. scattering characteristics similar to that of soft tissue<br>D. density similar to that of soft tissue | 2. D, density similar to that of soft tissue. The density of the material within a tissue equivalent phantom is not important. The other three characteristics of the phantom must be similar to that of soft tissue. |
| 3. What form of resolution is evaluated by measuring the width of reflections arising from small, point targets?<br>A. lateral resolution<br>B. axial resolution<br>C. temporal resolution<br>D. elevational resolution                                                                                         | 3. A, lateral resolution. Lateral resolution can be evaluated by measuring the width of reflections on the display that are created by point targets in the phantom.                                                  |
| 4. What form of resolution is evaluated by visualizing closely spaced pins that are parallel to the sound beam's main axis?<br>A. lateral resolution<br>B. axial resolution<br>C. temporal resolution<br>D. elevational resolution                                                                              | 4. B, axial resolution. Axial resolution is the smallest distance at which two pins positioned parallel to the sound beam are displayed as two distinct echoes.                                                       |
| 5. At what interval should quality assurance evaluations be performed?<br>A. weekly<br>B. daily<br>C. routinely<br>D. periodically                                                                                                                                                                              | 5. C, routinely. Quality assurance evaluations should be performed routinely.                                                                                                                                         |

# Sonographers in the Clinical Setting

## Principles of Bioethics

Many bioethics principles are self-evident; for example, the concept that a physician should not harm a patient, or should develop a care plan that provides the most benefit to the patient. If the patients have the mental capacity to do so, they must indicate a willingness to accept the proposed course.

## Major Principles of Medical Ethics

Four commonly accepted principles of health care ethics include:

1. respect for autonomy
2. nonmaleficence
3. beneficence
4. justice

## 1. Respect for Autonomy

Respect for autonomy means that the patient has the capacity to act intentionally, with understanding, and with free will. This principle is the basis of **informed consent**. In making voluntary, knowledgeable decisions, the patient is assumed to be of sound mind.

## 2. Nonmaleficence

The principle of nonmaleficence requires that we avoid needless harm or injury to the patient, whether by action or inaction. Imposing careless or unreasonable risk of harm on a person is negligence.

Nonmaleficence requires medical competence. Although medical mistakes do occur, this principle reinforces the commitment of health care professionals to protect their patients from harm.

## 3. Beneficence

The actions of health care providers should benefit the patient. This duty extends from individual patients to our entire community. It includes improving a patient's health, as well as preventing disease in the general population.

## 4. Justice

Justice in health care is usually defined as fairness. Generally, people who are equals should qualify for equal treatment, regardless of age, gender, educational background, and other factors.



## Informed Consent

**Informed consent** is the process by which patients are educated about the essentials of a medical procedure. This process allows them to make an informed, educated, and voluntary decision about the health care they are to receive.

The most important goal of informed consent is for patients to have an opportunity to be a knowledgeable participant in their health care decisions. Complete informed consent generally includes the following:

- the nature of the procedure
- reasonable alternatives
- the risks, benefits, and uncertainties related to each alternative
- assessment of the patient's understanding
- the patient's acceptance

For a patient's consent to be valid, the patient must be considered competent to make the decision and the consent must be voluntary. Since the patient's comprehension is equally as important as the information provided, the discussion should be in layperson's terms and the patient's understanding should be assessed throughout the process.

### *When is it appropriate to question a patient's ability to participate in decision making?*

If a patient is underage (typically under 18 years old), the patient's guardian must provide consent for the patient.

If the patient is incapacitated or incapable of providing consent, the patient's guardian or surrogate decision maker must provide consent.

If the patient does not speak English, the assistance of a translator may be necessary to obtain the patient's consent. It is preferable that the translator be hospital approved. A bilingual family member or other person can communicate with the patient as long as the patient has signed a HIPAA-compliant release form to proactively authorize ongoing involvement of a family member. However, only the patient can provide consent.

## Revocation of Consent

A patient may withdraw previously granted consent at any time. The sonographer must respect this decision and promptly bring the exam to a close. This should be done without exposing the patient to any additional risks or threats to safety.

## Patient–Sonographer Interaction

*What should the sonographer do when first meeting a patient?*

Upon meeting a patient:

1. Treat the patient respectfully.  
Introduce yourself, and describe the procedure and your role in performing it.
2. Identify the patient.  
If possible, use the patient's wristband for identification. If there is no wristband, it is acceptable to include patients in their own identification. For example, ask the patient for a birth date or full name.

If a sedated patient arrives without a wristband, call the nurse. The patient may be sent back to the floor and the study rescheduled when the patient has appropriate identification. It is inappropriate for the sonographer to cancel the exam. Ordering or canceling an examination is outside the sonographer's scope of practice.

## Interpretation of the Exam

In order to produce a diagnostic examination, a sonographer must be knowledgeable of abnormal and normal sonographic findings. Sonographers must be aware of and follow departmental guidelines when providing

their preliminary findings of the exam to a physician. However, sonographers should refrain from providing a clinical interpretation or discussing the findings directly with the patient. In fact, in some states, these acts may be considered the unauthorized practice of medicine.

## Patient Dignity

Dignity is defined as the quality of being worthy, honored, or esteemed. Every patient has a right to be treated in a dignified manner, one that is respectful and ethical.

Dignity includes a patient's perception of being in control and having self worth. Factors that make a patient vulnerable to a loss of dignity include advanced age, infirmity, and lack of privacy.

## Sonographer–Work Environment Interaction

No matter what we do, it is important to be safe, comfortable, and free from work-related injuries.

*What is ergonomics?*

**Ergonomics** studies the interaction between the sonographer, patient, and equipment in order to optimize the well-being of sonographers in their professional environment.



Sonographers must be in good physical shape and have full use of their hands, wrists, and shoulders. More than 3 out of 4 sonographers experience pain from work related musculoskeletal injury. Nearly 20% of sonographers end their careers as a result of such injuries. The Occupational Safety and Health Administration (OSHA) and the Society of Diagnostic Medical Sonography (SDMS) have formed an alliance, with goals of reducing and preventing work related musculoskeletal disorders.

### Causes of Injury

The causes of such injuries include repetitive motions, forceful or awkward movements, poor posture, improper positioning, strain, and pressure on joints for extended periods.

### Ergonomic Devices

Adaptive ergonomic devices have been designed and created for the sonographer. These devices include wrist support braces, adaptive support cushions, cable braces to keep the cable out of the sonographer's way, ergonomic transducer design, chairs with adjustable armrests and footrests, and bed designs with expanded adjustment options. Most importantly, control panel and monitor articulation (swivel and extension) allow the sonographer to maintain the recommended wrist, neck, eye, and body positions. Educational programs on proper techniques and exercise protocols are also available for sonographers.

### Best Practices

In addition to ergonomically designed systems, the sonographer should follow best practices. These include keeping your arm close to the body, staying close to the patient, positioning the system's monitor directly in front of you and at eye level, minimizing the extent of twisting or bending over, using proper sitting positions, holding the probe using a whole hand grip (palmar grip) rather than just the fingers (pinch grip), keeping the wrist in a neutral position, and using proper foot support. It is beneficial to maintain neutral positions that avoid stress and fatigue. Implementation of a successful ergonomic program can have a positive effect on the sonographer and improve patient care.

### Laboratory Policies and Procedures

Laboratory policies and procedures must include standards for ergonomics and sonographer health. Routine lab operation should include educational programs regarding best practices, proper use of equipment, and safety concerns. Annual continuing medical education regarding ergonomics is essential.

Effective patient scheduling can also reduce workplace injuries. Avoid scheduling the same type of exam consecutively to minimize strain and repetitive motion for extended periods. Limit the number of studies each day and incorporate non-scanning activities between studies.



## Standard Precautions

Standard precautions are a set of guidelines to minimize the exposure and risk of health care workers when in contact with a patient. Standard precautions are based on the idea that all patients should be treated as potentially infectious.

Standard precautions are an extension and clarification of universal precautions. Universal precautions were originally developed in the 1980s to minimize the risk of patients to HIV, HBV and other bloodborne pathogens.

All health care workers should routinely practice good hygiene habits, which include hand washing and the use of appropriate barrier precautions to prevent skin and mucous membrane exposure during contact with any patient's blood or body fluids. This includes the use of appropriate personal protective equipment such as gloves, gowns, eye wear and face masks whenever exposure to patients' bodily fluids is anticipated.

### *To what do standard precautions apply?*

Standard precautions apply over a very broad range: all body fluids, secretions, excretions, mucous membranes, airborne particles, and to nonintact skin. Standard precautions also apply to any items soiled with these substances.

## OSHA Implementation of Universal Precautions

The **Occupational Safety and Health Administration (OSHA)** presents the following implementation of the universal precautions:

1. All work activities should be classified according to the potential for exposure. Tasks with a greater potential for exposure have a greater need for appropriate protective equipment. At a minimum, gloves, protective clothing, and eye protection should be worn at all times when there is a reasonable potential for exposure.
2. A detailed work practice program should be developed that includes standard operating procedures (SOPs) for all activities that have the potential for exposure. Once these procedures are developed, a worker education program is implemented to assure familiarity with work practices for potentially exposed workers. Workers should not engage in tasks or activities that potentially put them at risk of exposure before receiving pertinent training. This training includes safe work practices and the use of protective equipment.
3. The employer should monitor workers to ensure that the required work practices are observed and that protective clothing and equipment are provided and properly used. Records documenting the procedures

and criteria used to assess the risk of job activities should be maintained. Copies of all standard operating procedures for tasks or activities that involve exposure to blood or other body fluids should also be kept on file, and made accessible to employees. In addition, training records should be kept.

## Review: Sonographers in the Clinical Setting

| Questions                                                                                                                                                                                     | Answers                                                                                                                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| 1. Which of the following provides the basis for informed consent?<br>A. notice<br>B. a contract<br>C. autonomy<br>D. beneficence                                                             | 1. C, autonomy. Autonomy is the ability to act intentionally, with understanding. This serves as the foundation for informed consent. |
| 2. Which of the following terms is defined by avoidance of unnecessary risk, harm, or needless injury?<br>A. nonmaleficence<br>B. beneficence<br>C. justice<br>D. autonomy                    | 2. <del>B</del> <sup>A</sup> , nonmaleficence.                                                                                        |
| 3. Which of the following terms describes the value that the actions of health care providers should benefit the patient?<br>A. nonmaleficence<br>B. beneficence<br>C. justice<br>D. autonomy | 3. B, beneficence.                                                                                                                    |

| Questions                                                                                                                                                                                                                                                                     | Answers                                                                                                                                                                                        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>4. Which one of these terms is not associated with informed consent?</p> <p>A. describing reasonable alternatives</p> <p>B. the patient's acceptance</p> <p>C. evaluation of the patient's understanding</p> <p>D. justice</p>                                             | <p>4. D is not associated with informed consent. Justice is a core value of medicine, not one of informed consent.</p>                                                                         |
| <p>5. When can a patient revoke consent?</p> <p>A. prior to the start of the procedure</p> <p>B. four hours prior to the procedure</p> <p>C. at any time, even during the procedure</p> <p>D. never</p>                                                                       | <p>5. C, at any time. Although choices A, B, and C are correct, the best choice is C. Patients may revoke their consent at any time.</p>                                                       |
| <p>6. Following the revocation of consent, when should a sonographer terminate the exam?</p> <p>A. immediately</p> <p>B. after all of the diagnostic information is obtained</p> <p>C. after the physician is notified</p> <p>D. at the first opportunity when it is safe</p> | <p>6. D, at the first safe opportunity. Even after revocation of consent, the procedure should only be terminated without exposing the patient to any additional risk or threat to safety.</p> |
| <p>7. True or False. A patient only communicates in a foreign language. It is acceptable to speak to a bilingual family member and obtain consent from the relative.</p>                                                                                                      | <p>7. False. Under these conditions, consent must be obtained from the patient, not from the family member.</p>                                                                                |
| <p>8. True or False. A patient only communicates in a foreign language. It is acceptable to have a bilingual family member serve as an interpreter, speak to the patient, and obtain consent from the patient.</p>                                                            | <p>8. True. An interpreter may be used to provide effective communication between a patient and a health care provider as long as the patient has signed a HIPAA-compliant release form.</p>   |
| <p>9. Which of the following is least likely to make a patient experience a loss of dignity?</p> <p>A. advanced age</p> <p>B. sickness</p> <p>C. lack of privacy</p> <p>D. sedation</p>                                                                                       | <p>9. D, sedation. Lack of dignity is not associated with sedation. Dignity is a state in which a person feels valued and worthy.</p>                                                          |



| Questions                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10. True or False. A sonographer with advanced practitioner status can provide her impression of a study to the patient.                                                                                                                         | 10. False. Sonographers may provide a preliminary report to a physician, but should refrain from providing that information directly to the patient.                                   |
| 11. Which of the following is the best and most appropriate action of a sonographer?<br>A. hand washing before an exam<br>B. hand washing after an exam<br>C. hand washing before and after an exam<br>D. using sterile technique during an exam | 11. C, hand washing before and after an exam. This is the most reasonable of the available choices. Sterile technique during a routine sonographic procedure is not necessary.         |
| 12. What is the first action of sonographers upon entering a patient's room?<br>A. introduce themselves to the patient<br>B. plug in the ultrasound system<br>C. check the patient's wristband<br>D. wash their hands                            | 12. A. It is important to treat patients with respect. Therefore, the first action should be to introduce themselves to the patient.                                                   |
| 13. A patient arrives at the ultrasound department. The patient does not have a wristband and is sedated. What should the sonographer do?<br>A. call the nurse<br>B. perform the study<br>C. cancel the study<br>D. reschedule the study         | 13. A. When sedated patients do not have proper identification, it is best to call the nurse. Generally, sonographers do not have the authority to order or cancel an ultrasound exam. |
| 14. True or False. Informed consent must always be obtained from the patient.                                                                                                                                                                    | 14. False. Patients must have the capacity to provide consent. For example, when a patient has a legal guardian, the guardian can provide the consent to treat.                        |
| 15. What is the study of the relationship between a worker and her environment called?<br>A. pathology<br>B. psychology<br>C. ergonomics<br>D. best practices                                                                                    | 15. C. Ergonomics studies the interaction between people and their work environment.                                                                                                   |

| Questions                                                                                                                                                                                                                                                | Answers                                                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>16. Guidelines to minimize the risk of health care workers to contract bloodborne infection have been developed. What are these guidelines called?</p> <p>A. OSHA guidelines<br/>B. standard precautions<br/>C. beneficence<br/>D. best practices</p> | <p>16. B, standard precautions. Standard precautions are guidelines to reduce the risk of health care workers to bloodborne infection.</p>     |
| <p>17. What percentage of sonographers are thought to experience musculoskeletal pain related to work?</p> <p>A. 20%<br/>B. 40%<br/>C. 60%<br/>D. 80%</p>                                                                                                | <p>17. D, 80%. Of the available choices, 80% of sonographers are affected. Approximately 20% will end their careers due to these problems.</p> |
| <p>18. All of the following can reduce workplace injuries except _____.</p> <p>A. patient scheduling<br/>B. proper use of equipment<br/>C. educational programming<br/>D. patient positioning<br/>E. none of the above</p>                               | <p>18. E, none of the above. All of these choices can reduce the incidence of workplace injury.</p>                                            |

## Bioeffects

Since the majority of the sound energy entering the body remains there, it is important to know the output of ultrasound systems. Several instruments can measure the sound energy produced by transducers. These instruments are generally used by scientists and engineers, rather than by clinical personnel.

### Hydrophone

The hydrophone, or **microprobe**, is similar to a small hypodermic needle with a tiny piece of piezoelectric material attached to its end. A wire connects the PZT crystal to an oscilloscope (see Fig. 24.1).

The hydrophone is placed in the sound beam created by the ultrasound transducer. A voltage from the hydrophone relates to the sound beam's pressure and is displayed on the oscilloscope. Since the hydrophone is small, the acoustic pressure is measured at **specific locations** within the sound beam.

★ Hydrophone measures pressure at specific locations ★



**Fig. 24.1** A hydrophone is a small transducer that measures the characteristics of a sound beam.



By moving the hydrophone to numerous locations while measuring the acoustic pressure, one can determine the sound beam's shape.

The hydrophone also measures the period, pulse repetition period, PRF, and pulse duration.

A hydrophone may be calibrated, thereby providing a known relationship between the acoustic pressure signal and the voltage created by the PZT. Intensities and other output measures can be derived from the signals from a **calibrated hydrophone**.

In general, transducer output is lowest when performing gray scale anatomic imaging and highest when performing pulsed Doppler. The outputs when performing color flow Doppler and M-mode lie between these values.

Another form of hydrophone is constructed from a very thin membrane of piezoelectric plastic (see Fig. 24.2). Only a very small area, located in the center of the membrane, is pressure sensitive.



Fig. 24.2 A membrane hydrophone.

## Radiation Force

A transducer's sound beam creates a very small, but measurable force on any target that it strikes. If the target is a balance or a float, the measured force relates to the power in the beam. This is also called a **feedback microbalance**. Essentially, when the sound beam is entirely absorbed or reflected by the target, the target acts as an extremely sensitive miniature postal scale.

## Acousto-Optics

Acousto-optics are based on the interaction of sound and light. A shadowing system, called a **Schlieren**, allows us to view the shape of a sound beam in a medium (see Fig. 24.3).

## Converting Sound Energy into Heat

Three devices measure the output of ultrasound transducers by **absorption**, the conversion of sound energy into heat:

1. calorimeter
2. thermocouple
3. liquid crystal.

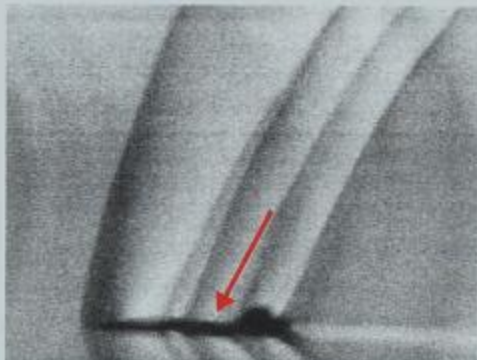


Fig. 24.3 Shock waves from a fighter jet (arrow) are examples of acousto-optics. They result from the interaction of sound and light.

## 1. Calorimeter

A calorimeter measures the total power in a sound beam through the process of **absorption**. Think of a calorimeter as a thermos bottle filled with absorbing material. The sound beam is directed into the calorimeter where the sound energy is converted into heat. The sound beam's total power is calculated by measuring the temperature rise and the time of heating.

Total Power measured

## 2. Thermocouple

A thermocouple is a tiny electronic thermometer. A dab of absorbing material is placed on the thermocouple. The thermocouple is inserted into the sound beam and the temperature is measured. The temperature rise is related to the power of the sound beam at the **particular location** where the device is positioned.

**Hint:** The thermocouple measures the sound beam's power at particular locations in the beam, whereas the calorimeter measures the power of the entire beam.

Power @ particular location

## 3. Liquid Crystals

Certain liquid crystals change color based on their temperature. When a sound beam strikes the crystals, the sound energy is absorbed. The change in crystal temperature causes a change in their color, providing insight into the shape and strength of the sound beam. Many of you may have seen "mood rings" or small "stress-o-meter" cards which change color based on temperature (see Fig. 24.4).



**Fig. 24.4** The temperature of the black pouch changes when your thumb is placed upon it. The pouch contains liquid crystals. Various thermal energy levels are represented by the colors.



## Risk–Benefit Relationship

A primary mandate regarding clinical ultrasound is that the **benefits** to the patient **must outweigh the risks** of the exam.

Obstetrics and fetal medicine are common applications of diagnostic sonography. Even after years of clinical use, there is no confirmation of harm resulting from its use.

Low intensity ultrasound has no known bioeffects.

Extremely high ultrasound intensities damage biologic tissues. However, there are no known cases of diagnostic imaging at standard intensities in the absence of contrast agents resulting in biological effects and tissue injury.

Under controlled circumstances, bioeffects are beneficial. For example, therapeutic ultrasound is widely used to treat muscular injury.

## Dosimetry

**Dosimetry** is the science of identifying and measuring the characteristics of an ultrasound beam that are relevant to its potential for producing biological effects.

Although there has been significant research, investigators continue to study the potential biological effects of ultrasound.

## In Vivo and In Vitro

Bioeffects research may be conducted in two broad areas, *in vivo* and *in vitro*.

### In vivo

*In vivo* research is performed **within the living body** of an animal or a plant. The literal meaning of *in vivo* is “in the living.” Studying the effects of ultrasound exposure on the lung tissue of a laboratory rat is an example of *in vivo* research.

### In vitro

*In vitro* research is performed **outside the living body** and in an artificial environment. The literal meaning of *in vitro* is “in glass.” A computer model estimating the temperature elevation of tissues during exposure to ultrasound is an example of *in vitro* research.

*In vitro* or “out of the body” studies are important as they provide the opportunity to perform research that would be impossible with live, human subjects. The challenge is to meaningfully relate *in vitro* results to the clinical setting.

*In vitro* research indicates that very high intensities can cause genetic damage and cell death.

## AIUM Statement on In Vitro Bioeffects

Summary statements from the AIUM statement on *in vitro* bioeffects are:

- *In vitro* bioeffects research is important.
- *In vitro* bioeffects are **real** even though they may not apply to the clinical setting.
- *In vitro* bioeffect research that claims direct clinical significance (without *in vivo* validation) should be viewed with caution.

SPTA

720 mW/cm<sup>2</sup>

100 mW/cm<sup>2</sup> unfocused

1 W/cm<sup>2</sup> focused  
(1,000 mW/cm<sup>2</sup>)

### American Institute of Ultrasound in Medicine—In Vitro Biological Effects

Approved March 19, 2007

*It is often difficult to evaluate reports of ultrasonically induced in vitro biological effects with respect to their clinical significance. The predominant physical and biological interactions and mechanisms involved in an in vitro effect may not pertain to the in vivo situation. Nevertheless, an in vitro effect must be regarded as a real biological effect.*

*Results from in vitro experiments suggest new endpoints and serve as a basis for design of in vivo experiments. In vitro studies provide the capability to control experimental variables that may not be controllable in vivo and thus offer a means to explore and evaluate specific mechanisms and test hypotheses. Although they may have limited applicability to in vivo biological effects, such studies can disclose fundamental intercellular or intracellular effects of ultrasound.*

*While it is valid for authors to place their results in context and to suggest further relevant investigations, reports which do more than that should be viewed with caution.*

# Study Techniques

Two techniques used to study bioeffects are:

1. mechanistic approach
2. empirical approach

## 1. Mechanistic Approach

The mechanistic approach begins as a proposal that a specific mechanism has the potential to produce bioeffects. Based on that proposal, a theoretical analysis is performed to estimate the scope of the bioeffects at various exposure levels.

The **mechanistic** approach searches for a relationship between **cause and effect**.

## 2. Empirical Approach

The empirical approach is based on the acquisition and review of information from patients or animals exposed to ultrasound. The research seeks a relationship between the exposure to ultrasound and the effects of that exposure.

The **empirical** approach searches for a relationship between **exposure and response**.

Table 24.1 Strengths (+) and Weaknesses (-)

| Mechanistic                                                                                    | Empirical                                                                                    |
|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• Broad exposure range can be evaluated (+).</li></ul>   | <ul style="list-style-type: none"><li>• No need to understand mechanism (+ and -).</li></ul> |
| <ul style="list-style-type: none"><li>• Uncertainty about assumptions (-).</li></ul>           | <ul style="list-style-type: none"><li>• Biological significance is obvious (+).</li></ul>    |
| <ul style="list-style-type: none"><li>• Are other mechanisms involved (-)?</li></ul>           | <ul style="list-style-type: none"><li>• Species differences may alter results (-).</li></ul> |
| <ul style="list-style-type: none"><li>• Is the bioeffect clinically significant (-)?</li></ul> |                                                                                              |

*Which of the study techniques, mechanistic or empirical, is best with regard to ultrasound bioeffects?*

Both mechanistic and empirical research techniques have merit. There are strengths and weaknesses for each. The strongest conclusions are made when the mechanistic and empirical conclusions are in agreement.



## Mechanisms of Bioeffects

Two important bioeffects mechanisms are:

1. thermal
2. cavitation (nonthermal)

### 1. Thermal Mechanism

The **thermal mechanism** proposes that bioeffects result from tissue temperature elevation.

The rationale for studying thermal effects are:

- As sound propagates in the body, energy is converted into heat.
- Core temperature is regulated at 37° C. Life processes may not function normally at other temperatures.

On the other hand, tissue temperatures are elevated routinely in our daily lives without any adverse effects. These activities include exercising, sunbathing, and fever.

### Thermal Index

The **thermal index**, or TI, is a useful predictor of maximum temperature increase under most clinically relevant conditions.

Thermal index is reported in three forms:

1. **TIS**, or soft tissue thermal index, assumes that sound is traveling in soft tissue.
2. **TIB**, or bone thermal index, assumes that bone is at or near the focus of the sound beam.
3. **TIC**, or cranial bone thermal index, assumes that cranial bone is in the sound beam's near field.

These thermal indices are the best measurements or estimates of *in vivo* tissue temperature elevation.

### Thermal Mechanism—Empirical Findings

Serious tissue damage occurs from prolonged and excessive elevation of tissue temperature. A 2° to 4° rise in testicular temperature can cause infertility.

Tissue heating is related to the output characteristics of the transducer and the properties of the tissues.

A combination of **temperature** and **exposure time** determine the likelihood of harmful bioeffects. With higher temperatures, harmful effects can occur with shorter exposure times.

Maximal heating is related to the beam's **SPTA intensity**, and the current FDA regulatory limit is  $720 \text{ mW/cm}^2$ , SPTA. In general, temperature elevations become progressively greater from gray scale imaging to color Doppler to spectral Doppler.

No confirmed bioeffects have been reported for temperature elevations of up to  $2^\circ \text{C}$  above normal for exposures of less than 50 hours.

Fetal and neonatal tissues appear less tolerant of tissue heating than adult tissues. Numerous fetal defects resulting from temperature elevation have been documented. None have been observed at temperatures less than  $39^\circ \text{C}$ .

Bone absorbs more acoustic energy than soft tissue. Therefore, the temperature rise in soft tissues near bone is significantly higher than in other locations. Circumstances wherein ultrasound strikes fetal bone deserve special attention.

### Thermal Mechanism—Mechanistic Data

Theoretical models appear to correlate with experimental data even though:

- the ultrasound beam is quite complex
- diagnostic equipment is diverse
- tissue characteristics are different

## American Institute of Ultrasound in Medicine—Conclusions Regarding Heat

Approved 2009

1. Excessive temperature increase can result in toxic effects in mammalian systems. The biological effects observed depend on many factors, such as the exposure duration, the type of tissue exposed, its cellular proliferation rate, and its potential for regeneration. Age and stage of development are important factors when considering fetal and neonatal safety. Temperature increases of several degrees Celsius above the normal core range can occur naturally. The probability of an adverse biological effect increases with the duration of the temperature rise.

The entire AIUM statement of Conclusions Regarding Heat appears at [www.aium.org/publications/statements.asp](http://www.aium.org/publications/statements.asp).

## 2. Nonthermal Mechanism

**Nonthermal or mechanical mechanisms** consist of cavitation and radiation force.

**Radiation force** is exerted by a sound beam on tissues. Shear stresses and streaming of fluids can distort or disturb biologic structures.

**Cavitation** is the interaction of sound waves with microscopic, stabilized, gas bubbles in the tissues. These bubbles are known as **gaseous nuclei**. Cavitation also describes the creation of gaseous nuclei from dissolved gases in a fluid. These gaseous nuclei are found in tissues and are different than the gas bubbles introduced into the body as contrast agents.

which they occur, and materials in which they exist. The only cavitation bioeffect identified at intensities typical of diagnostic ultrasound are in tissues with a well defined population of stabilized gas bodies, such as lung.

Two forms of cavitation exist:

1. stable
2. transient

Uncertainty exists regarding the nature of these dissolved gases and gaseous nuclei with regard to their location, size, chemical composition, conditions under



## 1. Stable Cavitation

At lower MI levels, stable cavitation occurs. The gaseous nuclei tend to oscillate, or expand and contract. Bubbles that are a few millimeters in diameter might double in size but **do not burst**.

The bubbles intercept and absorb much of the acoustic energy.

The fluids surrounding the cells undergo **microstreaming** and the cells are exposed to **shear stresses**.

## 2. Transient Cavitation

At higher MI levels, transient cavitation may occur. Transient cavitation is bubble-bursting. Transient cavitation is also called inertial or normal cavitation.

Transient cavitation produces highly localized, violent effects, including:

- colossal temperatures
- shock waves (enormous pressures)

The destructive effects of transient cavitation are not considered clinically important since they are highly localized and affect few cells.

The pressure threshold for transient cavitation is only 10% higher than that required for stable cavitation.

Table 24.2 Stable vs. Transient Cavitation

| Stable                              | Transient                                |
|-------------------------------------|------------------------------------------|
|                                     | • also called normal or inertial         |
| • oscillating bubble                | • bursting bubble                        |
| • microstreaming and shear stresses | • shock waves and very high temperatures |
| • lower MI                          | • higher MI                              |

The full text of the American Institute of Ultrasound in Medicine's Conclusions Regarding Gas Body Contrast Agents appears at [www.aium.org/publications/statements.asp](http://www.aium.org/publications/statements.asp).

## Mechanical Index

A calculated number, called the **mechanical index**, or MI, is related to the likelihood of harmful bioeffects from cavitation. MI is the best indicator of these effects.

The mechanical index is related to two sound wave characteristics:

- peak rarefaction pressure, and
- lower frequency.

There is a greater likelihood of cavitation bioeffects, and a higher MI, with:

- additional negative pressure, and
- lower frequency.

The mathematics of MI have been previously described on page 279.

**Table 24.3 Mechanical Index**

| Lower MI           | Higher MI         |
|--------------------|-------------------|
| • less cavitation  | • more cavitation |
| • less pressure    | • more pressure   |
| • higher frequency | • lower frequency |

## Epidemiology

Epidemiology is a branch of medicine associated with **population studies**. It is **empirical**—that is, an exposure-response method—which utilizes clinical surveys.

When the occurrence rate of bioeffects is small, population studies require many subjects. The smaller the effect, the harder it is to detect.

Many epidemiologic studies deal with *in utero* fetal exposures to ultrasound because:

- a large percentage of pregnant women in the U.S. are scanned.
- ultrasound is routinely used during normal pregnancies. Even a small risk creates concern when a procedure is performed on individuals without disease.
- harmful effects, if present, have the potential to affect the fetus for life.

Epidemiologic studies have evaluated many characteristics including birth weight, length, head circumference, congenital abnormalities, Apgar scores, hearing, and infection.

Epidemiologic data indicate that ultrasound exposure is not associated with adverse fetal outcome.

## Limitations

Three limitations of epidemiologic studies are:

- Studies are often **retrospective** or “backward looking.” The information is obtained from old medical records.
- Ambiguities may exist in the data, such as justification for the exam, gestational age, number of scans, technique, and exposure time.
- Risk factors other than exposure to ultrasound may precipitate a bad outcome in the fetus. These include environmental factors, poor nutrition, smoking, or alcohol and drug abuse.

## Prospective and Randomized Studies

The best epidemiologic studies are:

1. prospective
2. randomized

**1. Prospective studies are forward looking.** A protocol is established and specific information is systematically obtained. The advantage of a prospective study is that a complete and accurate compilation of meaningful information is obtained.

Retrospective studies are less desirable because data is collected from the past, and may be less accurate or incomplete. This makes interpretation more difficult.



**2. Randomized studies in ultrasound create two groups of patients.** One group is exposed to ultrasound and the other is not. The groups are otherwise as similar as possible. The advantage of a randomized study is that other risk factors that could negatively affect fetal outcome are present in both groups and can be accounted for.

### **American Institute of Ultrasound in Medicine—Conclusions Regarding Epidemiology for Obstetric Ultrasound**

*Approved March 27, 2010*

*Based on the epidemiologic data available and on current knowledge of interactive mechanisms, there is insufficient justification to warrant conclusion of a causal relationship between diagnostic ultrasound and recognized adverse effects in humans. Some studies have reported effects of exposure to diagnostic ultrasound during pregnancy, such as low birth weight, delayed speech, dyslexia and non-right-handedness. Other studies have not demonstrated such effects. The epidemiologic evidence is based primarily on exposure conditions prior to 1992, the year in which acoustic limits of ultrasound machines were substantially increased for fetal/obstetric applications.*

## **Clinical Safety and Prudent Use**

The conclusions of the AIUM include:

- No confirmed harmful bioeffects from exposure to diagnostic ultrasound have ever been reported.
- It is possible that bioeffects may be identified in the future.
- The **benefits** to the patient outweighs the risks.

- It is appropriate to use diagnostic ultrasound prudently to provide benefit to the patient.
- It is inappropriate to use diagnostic ultrasound in a non-medical setting for entertainment.

**Note:** It is *never* appropriate to use diagnostic ultrasound for entertainment.

## American Institute of Ultrasound in Medicine—Prudent Use and Clinical Safety

*Approved March 19, 2007*

*Diagnostic ultrasound has been in use since the late 1950s. Given its known benefits and recognized efficacy for medical diagnosis, including use during human pregnancy, the American Institute of Ultrasound in Medicine herein addresses the clinical safety of such use:*

*No independently confirmed adverse effects caused by exposure from present diagnostic ultrasound instruments have been reported in human patients in the absence of contrast agents. Biological effects (such as localized pulmonary bleeding) have been reported in mammalian systems at diagnostically relevant exposures but the clinical significance of such effects is not yet known. Ultrasound should be used by qualified health professionals to provide medical benefit to the patient.*

## American Institute of Ultrasound in Medicine—Prudent Use in Obstetrics

*Approved March 19, 2007*

*The AIUM advocates the responsible use of diagnostic ultrasound and strongly discourages the non-medical use of ultrasound for entertainment purposes. The use of ultrasound without a medical indication to view the fetus, obtain a picture of the fetus or determine the fetal gender is inappropriate and contrary to responsible medical practice. Ultrasound should be used by qualified health professionals to provide medical benefit to the patient.*

## Training and Research

The conclusions of the AIUM include:

- No confirmed bioeffects on patients of sonographers have been found with the use of diagnostic ultrasound.
- Experience with diagnostic ultrasound may differ from research and training, due in part to longer research exams and greater exposure.
- When used without direct medical benefit to the patient, the subject should be informed how the research study differs from standard diagnostic procedures.

### American Institute of Ultrasound in Medicine—Safety in Training and Research

*Approved March 19, 2007*

*Diagnostic ultrasound has been in use since the late 1950s. There are no confirmed adverse biological effects on patients resulting from this usage. Although no hazard has been identified that would preclude the prudent and conservative use of diagnostic ultrasound in education and research, experience from normal diagnostic practice may or may not be relevant to extended exposure times and altered exposure conditions. It is therefore considered appropriate to make the following recommendation:*

*When examinations are carried out for purposes of training or research, the subject should be informed of the anticipated exposure conditions and how these compare with normal diagnostic practice.*



## Electrical Safety

Several different instruments as well as the individual components of an ultrasound system may be linked to a patient at any given time. Precautions such as proper electrical grounding should always be taken to avoid electrical hazard. Instruments should be routinely checked for proper condition.

However, ultrasound systems present no special electrical safety hazards. Mechanically, the system should be inspected to assure proper physical status.

Since the transducer is in direct contact with the tissue, it exposes the patient to the greatest risk. However, this risk is small. The greatest risk arises from electrical shock from a cracked transducer housing. In addition, image quality may be compromised when using damaged transducers.

## Overall Safety Considerations

- Only perform studies with valid medical justification.
- Do not prolong studies without valid medical justification. Minimize exposure time while performing a complete diagnostic exam. Exam time is the primary determinant of patient exposure.
- Minimize patient exposure. Use the minimum output power and maximum amplification to optimize image quality. **ALARA**—As Low As Reasonably Achievable (see page 235).

### *In summary, be:*

- prudent
- careful
- judicious

*BE AN ULTRASOUND PROFESSIONAL!*

*Finished*

## Review: Bioeffects

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                              |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>1. A bioeffects report claims that obstetrical scanning may be harmful to a particular group of patients. What should be the response of the medical community?</p> <p>A. Perform the exams on all patients when the benefits are outweighed by the risks.</p> <p>B. Stop all diagnostic exams.</p> <p>C. Ignore the report.</p> <p>D. Halt all exams on this patient group.</p> <p>E. Perform exams on all patients when the benefits outweigh the risks.</p> | <p>1. E. One of the fundamental principles associated with the practice of medicine is balancing the benefits and risks to patients. A health care professional may proceed when the benefits surpass the risks.</p> |
| <p>2. The study of the characteristics, attributes, and quantities of a substance that induces bioeffects is called _____.</p>                                                                                                                                                                                                                                                                                                                                    | <p>2. Dosimetry.</p>                                                                                                                                                                                                 |
| <p>3. True or False. There are no bioeffects associated with ultrasound.</p>                                                                                                                                                                                                                                                                                                                                                                                      | <p>3. False.</p>                                                                                                                                                                                                     |
| <p>4. True or False. There are no bioeffects associated with ultrasound having characteristics typical of those in diagnostic medicine.</p>                                                                                                                                                                                                                                                                                                                       | <p>4. False.</p>                                                                                                                                                                                                     |
| <p>5. True or False. There are no <b>harmful</b> bioeffects associated with ultrasound having characteristics typical of those in diagnostic medicine.</p>                                                                                                                                                                                                                                                                                                        | <p>5. True. This question and the two preceding define the scope of bioeffects. Bioeffects are indeed present; however, <b>harmful</b> bioeffects are not typically observed with diagnostic ultrasound.</p>         |
| <p>6. True or False. Cavitation describes the interaction between sound waves and small gas bubbles that exist in tissues.</p>                                                                                                                                                                                                                                                                                                                                    | <p>6. True.</p>                                                                                                                                                                                                      |
| <p>7. True or False. There are two forms of cavitation: inertial and normal.</p>                                                                                                                                                                                                                                                                                                                                                                                  | <p>7. False. Inertial, transient, and normal cavitation are the same. The correct answer is stable and normal.</p>                                                                                                   |
| <p>8. True or False. Normal, transient, or inertial cavitation describes the bursting of microbubbles.</p>                                                                                                                                                                                                                                                                                                                                                        | <p>8. True.</p>                                                                                                                                                                                                      |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Answers                                                                                                                                          |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>9. Which of the following is <i>not</i> associated with the mechanistic approach?</p> <ul style="list-style-type: none"> <li>A. Identifying cause-effect relationship</li> <li>B. Proposing a specific means that could produce a bioeffect.</li> <li>C. Studying charts of patients who have been exposed to ultrasound.</li> <li>D. Analyzing the mechanism using theoretical methods.</li> <li>E. Reaching valid scientific conclusions</li> </ul>                                                                                                                    | <p>9. C. Evaluating patient charts is an element of the empirical study of bioeffects.</p>                                                       |
| <p>10. Veterans of a military operation suspect that they have been exposed to chemical warfare agents. The Veterans Administration Hospital surveyed these soldiers to identify the presence of symptoms and their prevalence. What form of medical investigation is this?</p>                                                                                                                                                                                                                                                                                             | <p>10. Empirical approach. Bioeffects are being investigated in an "exposure-response" context.</p>                                              |
| <p>11. Name the two important mechanisms likely to induce bioeffects.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <p>11. The two most important mechanisms associated with ultrasound-induced bioeffects are thermal and nonthermal (mechanical).</p>              |
| <p>12. Which statement allows us to conclude that diagnostic ultrasound does not injure tissues from temperature elevation?</p> <ul style="list-style-type: none"> <li>A. Death resulting from an ultrasound exam has never been reported.</li> <li>B. Mechanistic data indicate that diagnostic ultrasound is safe.</li> <li>C. Conclusions from empirical data and mechanistic data are consistent; that is, diagnostic ultrasound is unlikely to cause thermally induced bioeffects.</li> <li>D. Patients do not complain of burning during ultrasound exams.</li> </ul> | <p>12. C. Scientific conclusions are strongly justified when empirical and mechanistic investigations reach conclusions that are consistent.</p> |
| <p>13. Which modality is associated with the lowest tissue temperature elevation?</p> <ul style="list-style-type: none"> <li>A. pulsed Doppler</li> <li>B. color flow Doppler</li> <li>C. gray scale imaging</li> </ul>                                                                                                                                                                                                                                                                                                                                                     | <p>13. C, gray scale imaging. In general, tissue temperature elevations are lowest with gray scale anatomic imaging.</p>                         |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                               |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>14. Which ultrasound modality is associated with the highest tissue temperature elevation?</p> <p>A. pulsed Doppler<br/>B. color flow Doppler<br/>C. gray scale imaging</p>                                                                                                                                                                                                                                                                                                                                                                  | <p>14. A, pulsed Doppler. Of the available choices, tissue temperature elevations are highest with pulsed Doppler.</p>                                                                                                |
| <p>15. True or False. Stable cavitation describes the rhythmic swelling and shrinking of gaseous nuclei.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                    | <p>15. True. With stable cavitation, the microbubbles do not burst.</p>                                                                                                                                               |
| <p>16. The primary investigative technique of epidemiology is:</p> <p>A. computer modeling<br/>B. library research<br/>C. reviewing data from patients<br/>D. performing animal experiments</p>                                                                                                                                                                                                                                                                                                                                                 | <p>16. C, reviewing data from patients.</p>                                                                                                                                                                           |
| <p>17. Which of the following is <i>not</i> a limitation of epidemiological studies?</p> <p>A. Medical charts are sometimes incomplete or inaccurate.<br/>B. Other factors, unrelated to the study's ultimate goal, must be accounted for.<br/>C. When the bioeffect rate is small, numerous patients must be studied.<br/>D. Even when a bioeffect is identified, the investigator is still unsure of the specific reason for its occurrence.<br/>E. It does not provide greater understanding of the biologic significance of bioeffects.</p> | <p>17. E is not a limitation. The greatest strength of epidemiological research is its dependence on clinical significance. If the bioeffect is observed in patients, then we are sure of its clinical relevance.</p> |
| <p>18. True or False. The intensity limit established for diagnostic ultrasound is higher for focused sound beams than for broad, unfocused beams.</p>                                                                                                                                                                                                                                                                                                                                                                                          | <p>18. True. Broad, unfocused sound beams cause greater tissue heating. The maximum intensity limit for these beams is therefore lower than that for focused beams.</p>                                               |
| <p>19. True or False. <i>In vitro</i> studies are performed exclusively on living animals.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <p>19. False. <i>In vitro</i> means literally "in glass."</p>                                                                                                                                                         |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 20. True or False. Bioeffects identified through <i>in vitro</i> research are not considered real.                                                                                                                                                                                                                                                                                                                                                               | 20. False. The AIUM conclusively states that <i>in vitro</i> bioeffects must be considered real; however, their clinical importance is unknown.                                                            |
| 21. Which measure of intensity is related most closely to tissue heating?<br>A. $I_m$<br>B. SATA<br>C. SPPA<br>D. SPTA<br>E. SPTP                                                                                                                                                                                                                                                                                                                                | 21. D. SPTA, spatial peak temporal average.                                                                                                                                                                |
| 22. The next step following the identification of an <i>in vitro</i> bioeffect is:<br>A. Propose <i>in vivo</i> research to evaluate the clinical significance of the bioeffect.<br>B. Cease performing clinical studies that may induce bioeffects <i>in vivo</i> .<br>C. Ignore the results: it's only an <i>in vitro</i> observation.<br>D. Continue with <i>in vitro</i> research.<br>E. Obtain an informed consent regarding this report from all patients. | 22. A. Further <i>in vivo</i> research should be performed to understand the impact of <i>in vitro</i> -identified bioeffects on living subjects.                                                          |
| 23. True or False. Exposing an individual to ultrasound from a diagnostic imaging system is never appropriate when there is absolutely no clinical benefit to that individual.                                                                                                                                                                                                                                                                                   | 23. False. It is appropriate to perform ultrasound studies for the sake of research and training even when no direct medical benefit is anticipated. Informed consent should be obtained from the subject. |
| 24. Which component of an ultrasound system is most likely to expose a patient to danger?<br>A. monitor<br>B. transducer<br>C. scan converter<br>D. pulser                                                                                                                                                                                                                                                                                                       | 24. B. Generally, the transducer is the component with the greatest potential for exposing a patient to risk. The likelihood of injury is minuscule, but the potential exists.                             |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Answers                                                                                                                                                                             |
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| <p>25. Which is generally true of diagnostic ultrasound?</p> <ul style="list-style-type: none"> <li>A. Harmful bioeffects do not occur, and it is unnecessary to discuss them.</li> <li>B. Harmful bioeffects do not occur, but it is irresponsible to ignore the possibility that they may.</li> <li>C. Harmful bioeffects are often seen, but the benefit to patients still outweighs the risk.</li> <li>D. Only new technologies such as 3-D or intravascular ultrasound need to be evaluated for bioeffects.</li> </ul> | <p>25. B. Diagnostic ultrasound has a remarkable safety record; however, we must always protect our patients from potential harm.</p>                                               |
| <p>26. Which of the following is an appropriate use of ultrasound in obstetrics?</p> <ul style="list-style-type: none"> <li>A. determine fetal gender</li> <li>B. viewing a fetus</li> <li>C. obtaining a picture of a fetus</li> <li>D. to provide medical benefit to the patient</li> </ul>                                                                                                                                                                                                                               | <p>26. D. The use of ultrasound is appropriate when providing medical benefit to the patient. Selections A, B, and C, are contrary to the responsible practice of medicine.</p>     |
| <p>27. Which of these factors are relevant with regard to the thermal mechanism of bioeffects?</p> <ul style="list-style-type: none"> <li>A. rarefactional pressure and frequency</li> <li>B. compression pressure and frequency</li> <li>C. temperature and exposure time</li> <li>D. SPTA intensity and spatial pulse length</li> </ul>                                                                                                                                                                                   | <p>27. C, temperature and exposure time. A combination of temperature and exposure time determine the likelihood of harmful bioeffects.</p>                                         |
| <p>28. What information should be provided to a patient when undergoing a study for the purpose of research or training?</p> <ul style="list-style-type: none"> <li>A. the anticipated exposure conditions and how these compare to normal diagnostic procedures</li> <li>B. the duration of the exam</li> <li>C. the research study's goal</li> <li>D. bioeffects associated with the technique</li> </ul>                                                                                                                 | <p>28. A. A subject of a research or training exam should be informed of the exposure conditions and how they compare to those of a standard diagnostic ultrasound examination.</p> |
| <p>29. True or False. The transducer exposes a patient to the greatest risk.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                            | <p>29. True. Since the transducer is in direct contact with the patient, it exposes the patient to the greatest risk.</p>                                                           |





# Exam Review

| Questions                                                                                                                              | Answers                                                                                                                                                                                                                                                                                        |
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| <b>THE BASICS</b>                                                                                                                      |                                                                                                                                                                                                                                                                                                |
| 1. What is the vertical axis of a graph called?<br>A. z-axis<br>B. x-axis<br>C. y-axis<br>D. time-axis                                 | C. The vertical axis of a graph is called the y-axis and extends up and down.                                                                                                                                                                                                                  |
| 2. What is the name of the horizontal axis of a graph?<br>A. z-axis<br>B. x-axis<br>C. y-axis<br>D. red axis                           | B. The horizontal axis of a graph is the x-axis. The x-axis extends side to side.                                                                                                                                                                                                              |
| 3. How are scores on the ultrasound board exams related to study time?<br>A. inversely<br>B. conversely<br>C. directly<br>D. unrelated | C. Two variables are related when changes in one variable result in changes in the other. When the changes go in the same direction (both increase or both decrease), the variables are directly related. Since scores increase as study time increases, these variables are directly related. |

| Questions                                                                                                                                                                                                | Answers                                                                                                                                                                                                                         |
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| <p>4. How are caloric intake and weight related?</p> <p>A. inversely<br/>B. partially<br/>C. reciprocally<br/>D. directly</p>                                                                            | <p>D. These two terms are directly related. As food intake increases, weight increases. Similarly, as food intake decreases, weight decreases.</p>                                                                              |
| <p>5. How is weight related to a sonographer's time spent exercising?</p> <p>A. inversely<br/>B. conversely<br/>C. directly<br/>D. unrelated</p>                                                         | <p>A. Two variables are related when changes in one variable result in changes in the other. When the changes follow in the opposite direction (one increases as the other decreases), the variables are inversely related.</p> |
| <p>6. What is the reciprocal of 1,000?</p> <p>A. one-hundredth<br/>B. 1,000<br/>C. 0.001<br/>D. one-millionth</p>                                                                                        | <p>C. A pair of reciprocal numbers, when multiplied together, have a value of 1. In this case, <math>1,000 \times 0.001 = 1</math>.</p>                                                                                         |
| <p>7. What is the reciprocal of 5?</p> <p>A. one-hundredth<br/>B. 5<br/>C. 1/5<br/>D. one-millionth</p>                                                                                                  | <p>C. A pair of reciprocal numbers, when multiplied together, have a value of 1. In this case, <math>5 \times 1/5 = 1</math>.</p>                                                                                               |
| <p>8. What is the reciprocal of 1/10?</p> <p>A. one-hundredth<br/>B. 10<br/>C. 1/10<br/>D. one-millionth</p>                                                                                             | <p>B. A pair of reciprocal numbers, when multiplied together, have a value of 1. In this case, <math>10 \times 1/10 = 1</math>.</p>                                                                                             |
| <p>9. A sack contains 6 pounds of flour. The contents of the bag are increased by a factor of 5. How much flour is in the bag?</p> <p>A. 6 pounds<br/>B. 11 pounds<br/>C. 60 pounds<br/>D. 30 pounds</p> | <p>D. The term "increase by a factor" means to multiply.<br/><math>6 \times 5 = 30</math> pounds.</p>                                                                                                                           |

| Questions                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                |
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| <p>10. A bouquet has 30 flowers. The size of the bouquet is decreased by a factor of 3. How many flowers remain?</p> <p>A. 27<br/>B. 0<br/>C. 10<br/>D. 15</p>                                                                                    | <p>C. The term "decrease by a factor" means to divide.<br/><math>30 / 3 = 10</math>.</p>                                                                                                                                                                                                               |
| <p>11. Which of the following is <i>not</i> a measure of area?</p> <p>A. square cm<br/>B. meters squared<br/>C. cubic meters<br/>D. feet x feet</p>                                                                                               | <p>C. Cubic meters are not used to measure area; they are used to measure volume. An area is measured in units of distance squared. For example, a rectangle's area is its length multiplied by its width, and can be reported in square feet, <math>\text{in}^2</math>, or square miles.</p>          |
| <p>12. A sonographer measures the perimeter of an anatomical structure. Which of the following choices is a reasonable value for the measurement?</p> <p>A. <math>6 \text{ cm}^2</math><br/>B. 5 cc<br/>C. 15 mm<br/>D. 18 dB</p>                 | <p>C. "Perimeter" means the length of the outer boundary of a structure. For example, a square with an edge that is 5 inches long will have a perimeter measuring 20 inches (four sides, each with a length of 5 inches).</p> <p>Units of measurement in A, B, and D are not applicable to length.</p> |
| <p>13. What are the units associated with the circumference of a circle?</p> <p>A. mm<br/>B. <math>\text{mm}^2</math><br/>C. <math>\text{cm}^3</math><br/>D. <math>\text{m}^4</math></p>                                                          | <p>A. The circumference of a circle is the length of the circle's outer boundary and is measured in units of length.</p> <p>B and C are units of area and volume. D has units of length to the fourth power, which has no meaning in geometry.</p>                                                     |
| <p>14. The volume of a cystic structure is estimated from sonographic data. Which of the following is an acceptable measurement of this volume?</p> <p>A. 6<br/>B. 6 cm<br/>C. <math>6 \text{ cm}^2</math><br/>D. <math>6 \text{ cm}^3</math></p> | <p>D. The units of volume are length cubed, such as <math>\text{ft}^3</math> or cubic centimeters. Volume may also be expressed as length to the third power.</p> <p>A has no units, whereas B and C have units of length and area.</p>                                                                |

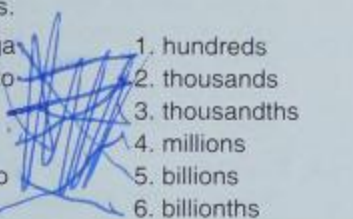
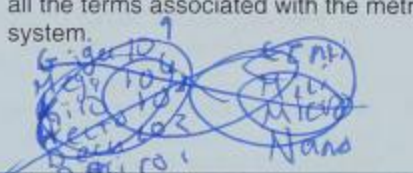


| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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| <p>15. The speed of red blood cells traveling through a blood vessel is 750 cm/sec. You are asked to measure this speed in miles per hour. What information would be sufficient for you to complete your task?</p> <p>A. how many seconds in a minute and how many blood cells in the vessel</p> <p>B. the number of miles in a meter</p> <p>C. how many seconds per hour and the number of miles in a centimeter</p> <p>D. the direction of red blood cell motion and the Doppler shift frequency</p> | <p>C. To convert one unit to another requires a factor that relates the two terms. For example, to change a measurement of length from feet into inches, we must know how many inches are in a foot. In this case, we are asked to convert cm per sec into miles per hour. Therefore, we require two pieces of information: the relationship between seconds and hours (relating one unit of time to another) and the relationship between miles and centimeters (relating one unit of distance to another). <i>When units are changed, the actual amount does not change.</i> For example, ten dimes provide the same purchasing power as four quarters. The units may be different, but the "total picture" remains the same.</p> |
| <p>16. How much bigger is one billion than one thousand?</p> <p>A. 1,000 times</p> <p>B. 1,000,000 times</p> <p>C. 10 times</p> <p>D. 10,000 times</p>                                                                                                                                                                                                                                                                                                                                                 | <p>B. A billion is one million times larger than a thousand. A million is 1,000,000.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

### METRIC SYSTEM

|                                                                                                                                                                                                                                             |                                                                                                                                                                                                        |
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| <p>17. Select the sequence that appears in increasing order.</p> <p>A. mega, kilo, hecto, milli, giga</p> <p>B. nano, milli, micro, deci, deca, mega</p> <p>C. centi, deci, deca, hecto</p> <p>D. milli, hecto, centi, deci, nano, giga</p> | <p>C. Centi means "one-hundredth", deci means "one-tenth", deca means "ten", and hecto means "hundred." Thus, this sequence is increasing, starting from the smallest and ending with the largest.</p> |
| <p>18. How many nanoseconds are in 7 seconds?</p> <p>A. 7,000,000</p> <p>B. 7,000,000,000</p> <p>C. 7 million</p> <p>D. 0.00000007</p>                                                                                                      | <p>B. Nano means billionth. There are one billion billionths in one second. Therefore, there are seven billion billionths in seven seconds.</p>                                                        |

Giga 10<sup>9</sup>  
 Mega 10<sup>6</sup>  
 Kilo 10<sup>3</sup>  
 Hecto 10<sup>2</sup>  
 Deci 10<sup>-1</sup>  
 Centi 10<sup>-2</sup>  
 Milli 10<sup>-3</sup>  
 Micro 10<sup>-6</sup>  
 Nano 10<sup>-9</sup>

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                              |
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| <p>19. The letters below represent the abbreviations for the prefixes of the metric system. Select the sequence that appears in <i>decreasing</i> order.</p> <p>A. m, k, M, g, da<br/>         B. g, m, k, d, <math>\mu</math><br/>         C. g, k, di, m, <math>\mu</math>, n<br/>         D. M, k, da, d, c</p>                                                                                                             | <p>D. M stands for mega and means "millions." k stands for kilo and means "thousands." da stands for deca and means "tens." d stands for deci and means "one-tenth." c stands for centi and means "one-hundredth." Thus, this sequence is of decreasing numbers.</p> |
| <p>20. Match the following prefixes with their meanings.</p> <p>A. mega<br/>         B. hecto<br/>         C. milli<br/>         D. kilo<br/>         E. nano<br/>         F. giga</p> <p>1. hundreds<br/>         2. thousands<br/>         3. thousandths<br/>         4. millions<br/>         5. billions<br/>         6. billionths</p>  | <p>A-4, B-1, C-3, D-2, E-6, F-5.</p> <p>You should be familiar with the abbreviations, prefixes, and meanings for all the terms associated with the metric system.</p>             |
| <p>21. Which term is the reciprocal of mega?</p> <p>A. nano<br/>         B. kilo<br/>         C. macro<br/>         D. micro</p>                                                                                                                                                                                                                                                                                               | <p>D. Mega means million. The reciprocal of million is millionth. Micro means millionth.</p>                                                                                                                                                                         |
| <p>22. How can the volume of an irregularly shaped object be measured most accurately?</p> <p>A. by visual inspection<br/>         B. by its weight<br/>         C. by immersing it in water<br/>         D. by ultrasound scanning</p>                                                                                                                                                                                        | <p>C. The volume of any object can be accurately measured by immersing it in water and measuring the volume of water that is displaced.</p>                                                                                                                          |
| SOUND WAVES                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                      |
| <p>23. What term is used to describe the effects of an ultrasound wave on living tissues?</p> <p>A. toxic effects<br/>         B. acoustic propagation properties<br/>         C. biological effects<br/>         D. transmission properties</p>                                                                                                                                                                               | <p>C. The effects of ultrasound on the tissues are called biological effects or bioeffects. There have been no confirmed bioeffects on humans with acoustic intensities typical of those used in diagnostic imaging.</p>                                             |

| Questions                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                              |
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| <p>24. As sound travels through a medium, what term describes the effects of the medium on the sound wave?</p> <p>A. toxic effects<br/>B. acoustic propagation properties<br/>C. bioeffects<br/>D. transmission properties</p> | <p><b>B.</b> Acoustic propagation properties describes the effects of the medium on the wave traveling through it. Acoustic means "sound." Propagation means "to travel."</p>                                                                                                                                                                        |
| <p>25. Which of the following is true of all waves?</p> <p>A. they travel through a medium<br/>B. all carry energy from one site to another<br/>C. their amplitudes do not change<br/>D. they travel in a straight line</p>    | <p><b>B.</b> Waves carry energy from one place to another. A is incorrect because some waves, such as light, can travel through a vacuum. C is incorrect because many waves get weaker as they travel. Certain waves do not travel in a straight line, so D is also incorrect.</p>                                                                   |
| <p>26. Which of the following types of waves do <i>not</i> require a medium in order to propagate? (More than one answer may be correct.)</p> <p>A. light<br/>B. heat<br/>C. sound<br/>D. television</p>                       | <p><b>A, B, and D.</b><br/>Sound cannot travel through a vacuum; it requires a medium in order to propagate. Other waveforms such as light, heat and TV waves are capable of traveling through a vacuum.</p>                                                                                                                                         |
| <p>27. Which of the following describes the characteristics of a sound wave?</p> <p>A. longitudinal, non-mechanical<br/>B. mechanical, transverse<br/>C. transverse, acoustic<br/>D. mechanical, longitudinal</p>              | <p><b>D.</b> Sound is a mechanical, longitudinal wave. A mechanical wave, such as sound, actually imparts energy to the molecules of the medium through which it travels. The molecules of the medium vibrate, striking their neighbors, which in turn vibrate. This chain reaction results in the acoustic energy traveling through the medium.</p> |
| <p>28. Sound is best described as ____.</p> <p>A. a series of compressions and rarefactions<br/>B. a transverse wave<br/>C. a wave that humans can hear<br/>D. an oblique displacement of acoustic energy</p>                  | <p><b>A.</b> Sound is composed of a series of compressions and rarefactions. Molecules in the medium are alternately squeezed together (compressed) and stretched apart (rarefied).</p>                                                                                                                                                              |



| Questions                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                              |
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| <p>29. All of the following are true about sound waves <i>except</i> _____.</p> <p>A. they are mechanical<br/>           B. they are transverse<br/>           C. they carry energy from place to place<br/>           D. they generally travel in a straight line</p>                | <p><b>B.</b> Sound waves are not transverse, they are longitudinal.</p>                                                                                                                                                                                              |
| Which of the following 8 selections are acoustic variables? (True or False)                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                      |
| 30. Frequency                                                                                                                                                                                                                                                                         | <b>False.</b>                                                                                                                                                                                                                                                        |
| 31. Pressure                                                                                                                                                                                                                                                                          | <b>True.</b>                                                                                                                                                                                                                                                         |
| 32. Propagation speed                                                                                                                                                                                                                                                                 | <b>False.</b>                                                                                                                                                                                                                                                        |
| 33. Wavelength                                                                                                                                                                                                                                                                        | <b>False.</b>                                                                                                                                                                                                                                                        |
| 34. Voltage                                                                                                                                                                                                                                                                           | <b>False.</b>                                                                                                                                                                                                                                                        |
| 35. Intensity                                                                                                                                                                                                                                                                         | <b>False.</b>                                                                                                                                                                                                                                                        |
| 36. Motion of particles in the wave                                                                                                                                                                                                                                                   | <b>True.</b>                                                                                                                                                                                                                                                         |
| 37. Density                                                                                                                                                                                                                                                                           | <p><b>True.</b> Acoustic variables identify certain wave as sound waves. These quantities are pressure, density and particle motion.</p>                                                                                                                             |
| <p>38. What are the units of a pressure measurement of an acoustic wave? (More than one answer may be correct.)</p> <p>A. atmospheres (atm)<br/>           B. pascals (Pa)<br/>           C. millimeters of mercury (mm Hg)<br/>           D. pounds/sq. inch (lb/in<sup>2</sup>)</p> | <p><b>A, B, C, and D.</b></p> <p>All of these terms are appropriate to represent pressure (just as weight can be reported with units of pounds, ounces, tons, or grams).</p> <p>However, the pressure of sound waves is most often reported in units of pascals.</p> |
| <p>39. Sound can be characterized as:</p> <p>A. energy flowing through a vacuum<br/>           B. a variable<br/>           C. cyclical oscillations in certain variables<br/>           D. a principle of acoustics</p>                                                              | <p><b>C.</b> Sound is a wave. A wave is the rhythmical variation throughout time.</p>                                                                                                                                                                                |

| Questions                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                    |
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| Match the 3 acoustic variables, pressure, density, and particle motion with their correct units. (More than one answer may be correct.)                                                                                                                                                        |                                                                                                                                                                                                                                            |
| A. $\text{lb/in}^3$<br>B. Fahrenheit degrees<br>C. miles<br>D. Pa                                                                                                                                                                                                                              | E. cm<br>F. Centigrade degrees<br>G. $\text{lb/in}^2$<br>H. $\text{kg/m}^3$                                                                                                                                                                |
| 40. Pressure                                                                                                                                                                                                                                                                                   | <b>D and G.</b><br>Units of pressure include pascals (Pa) and pounds per square inch ( $\text{lb/in}^2$ ).                                                                                                                                 |
| 41. Density                                                                                                                                                                                                                                                                                    | <b>A and H.</b><br>Density is the concentration of mass per unit of volume. Mass is measured in pounds (lbs) or kilograms (kg). Volume has units of length cubed, such as cubic inches ( $\text{in}^3$ ) or cubic meters ( $\text{m}^3$ ). |
| 42. Particle motion                                                                                                                                                                                                                                                                            | <b>C and E.</b><br>Particle motion is measured in units of distance, such as miles or cm. These choices are the only ones available that appear simply as distance.                                                                        |
| 43. A force is applied to a surface. If the force is tripled and the surface area over which the force is applied is also tripled, what is the new pressure?<br>A. three times larger than the original<br>B. one third of the original<br>C. six times more than the original<br>D. unchanged | <b>D.</b> Pressure is defined as an amount of force divided by the area to which it is applied. If the applied force is tripled, and at the same time, the area over which it is applied is tripled, then the pressure remains unchanged.  |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                               | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                   |
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| <p>44. A longitudinal wave propagates from east to west at a speed of 2 miles per hour. What is the direction of motion of the particles within the wave?</p> <ul style="list-style-type: none"><li>A. from east to west only</li><li>B. alternately from east to west and then from west to east</li><li>C. from north to south only</li><li>D. alternately from south to north and then from north to south</li></ul> | <p>B. A longitudinal wave is defined as a wave whose particles vibrate back and forth in the same direction that the wave is propagating. Since the wave is traveling from east to west, the particles in this wave will move alternately from east to west and then from west to east.</p>                                                                                                                                               |
| <p>45. The direction of motion of a particle in a wave is perpendicular to the direction of propagation of the wave. What type of wave is this?</p> <ul style="list-style-type: none"><li>A. longitudinal</li><li>B. acoustic</li><li>C. mechanical</li><li>D. transverse</li></ul>                                                                                                                                     | <p>D. A characteristic of transverse waves is that the direction of propagation is perpendicular to the direction of particle motion in the wave. Sound waves are not transverse, but rather longitudinal.</p>                                                                                                                                                                                                                            |
| <p>46. A particle within a transverse wave is traveling vertically. What is the direction of the wave's propagation?</p> <ul style="list-style-type: none"><li>A. horizontal</li><li>B. vertical</li><li>C. diagonal; both horizontal and vertical</li><li>D. cannot be determined</li></ul>                                                                                                                            | <p>A. The particles within a transverse wave travel in a direction that is perpendicular to the direction of propagation of the wave. If a transverse wave is traveling vertically, the particles in the wave are traveling horizontally. A water wave is a primarily a transverse wave. The wave propagates sideways along the surface of the water, while a ball floating on top of the water moves up and down as the wave passes.</p> |
| <p>47. Waves that exist at the same location and time will combine. What is this called?</p> <ul style="list-style-type: none"><li>A. inference</li><li>B. rarefaction</li><li>C. interference</li><li>D. longitudinal interaction</li></ul>                                                                                                                                                                            | <p>C. The combination of many waves into a single wave is called interference.</p>                                                                                                                                                                                                                                                                                                                                                        |



| Questions                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                                                              |
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| <p>48. Two waves arrive at the same location and interfere. The resultant sound wave is smaller than either of the two original waves. What is this called?</p> <p>A. constructive interference<br/>B. angular interaction<br/>C. destructive interference<br/>D. in-phase waves</p> | <p>C. Destructive interference results when a pair of out-of-phase waves interfere with each other. The sum of the two out-of-phase waves has a smaller amplitude than at least one of the original waves.</p>                                                                                                                       |
| <p>49. A pair of waves are in phase. What occurs when these waves interfere?</p> <p>A. reflection<br/>B. constructive interference<br/>C. refraction<br/>D. destructive interference</p>                                                                                             | <p>B. Waves that are in phase constructively interfere with each other. The single wave that results from the combination of the two in-phase waves will always have a higher amplitude than either of the original waves.</p>                                                                                                       |
| <p><b>PERIOD and FREQUENCY</b></p>                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                      |
| <p>50. What is the range of periods commonly found in waves produced by ultrasound systems?</p> <p>A. 0.001 to 1 s<br/>B. 0.06 to 0.5 <math>\mu</math>s<br/>C. 0.2 to 1 ms<br/>D. 10 to 100 ns</p>                                                                                   | <p>B. Ultrasonic imaging waves have a period in the range of 0.06 to 0.5 <math>\mu</math>s. The period is the time of a single cycle. Period is the reciprocal of frequency. A wave with a frequency of 2 MHz has a period of 0.5 <math>\mu</math>sec. A wave with a frequency of 15 MHz has a period of 0.06 <math>\mu</math>s.</p> |
| <p>51. With standard ultrasonic imaging, what happens to the period of a wave as it propagates?</p> <p>A. increases<br/>B. decreases<br/>C. remains the same</p>                                                                                                                     | <p>C. Certain parameters of a wave change as the wave travels through the body. However, the period and the frequency of a wave typically remain constant as a sound wave propagates.</p>                                                                                                                                            |
| <p>52. What determines the period of an ultrasound wave?</p> <p>A. the transducer<br/>B. the medium through which the sound travels<br/>C. both A and B<br/>D. neither choice A nor B</p>                                                                                            | <p>A. The sound source (the transducer) that produces an acoustic signal determines the period of a wave. The wave's period is unrelated to the medium through which the sound travels, and will not change as the wave moves from one medium to another.</p>                                                                        |

| Questions                                                                                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                                                                                                              |
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| <p>53. Which of the following units are appropriate to describe the period of an acoustic wave? (More than one answer may be correct.)</p> <ul style="list-style-type: none"> <li>A. minutes</li> <li>B. microseconds</li> <li>C. meters</li> <li>D. mm/<math>\mu</math>s</li> <li>E. cubic centimeters</li> </ul> | <p><b>A and B.</b></p> <p>The period of a wave is defined as the time that elapses as a wave oscillates through a single cycle. The units for period must be a measure of time, such as minutes or seconds. A and B are units of time. The incorrect selections C, D, and E are units of distance, speed, and volume, respectively.</p>                                                              |
| <p>54. True or False? The sonographer has the ability to alter the period of an ultrasound wave that is produced by a basic transducer.</p>                                                                                                                                                                        | <p><b>False.</b> The sonographer cannot adjust the period (or frequency) of a wave produced by a basic transducer. Think of striking a key on a piano. The frequency of sound created by striking a single key is constant. If the sound beam's frequency and period are not suited for the particular type of imaging, the sonographer must select a new transducer with a different frequency.</p> |
| <p>55. What term describes the number of cycles that an acoustic variable completes in a second?</p> <ul style="list-style-type: none"> <li>A. period</li> <li>B. frequency</li> <li>C. pulse repetition period</li> <li>D. variable rate</li> </ul>                                                               | <p><b>B.</b> This is the definition of the term frequency. Frequency can also be thought of as the number of regularly occurring events in a specific time.</p>                                                                                                                                                                                                                                      |
| <p>56. Which of the following <i>cannot</i> be considered a unit of frequency?</p> <ul style="list-style-type: none"> <li>A. per day</li> <li>B. cycles/sec</li> <li>C. Hz</li> <li>D. hertz</li> <li>E. cycles</li> </ul>                                                                                         | <p><b>E.</b> The term cycles informs us of the number of events, but does not inform us of the duration of time required for those events to occur.</p> <p>Choice E is incomplete, and is not a unit of frequency. All the other choices reveal that a number of events took place in a specific time span.</p>                                                                                      |

| Questions                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                  |
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| <p>57. What is the range of frequencies emitted by transducers used in ultrasonic imaging?</p> <p>A. 1 to 3 MHz<br/>           B. 1 to 1,000 kHz<br/>           C. -10,000 to +10,000 Hz<br/>           D. 2,000,000 to 15,000,000 Hz</p> | <p>D. Frequencies commonly used in diagnostic imaging range from approximately 2 to 15 megahertz or 2 to 15 million cycles per second.</p>                                                                                                                                                               |
| <p>58. What establishes the frequency of an ultrasound wave?</p> <p>A. the transducer<br/>           B. the medium through which the sound travels<br/>           C. both A and B<br/>           D. neither choice A nor B</p>            | <p>A. When created by a transducer, an ultrasound wave has a specific frequency. The frequency is not determined by the medium through which the sound travels. Only the sound source (the transducer) establishes the wave's frequency.</p>                                                             |
| <p>59. True or False? With standard ultrasound pulses, the frequency of the ultrasound changes significantly as the wave propagates through the body.</p>                                                                                 | <p><b>False.</b> In diagnostic imaging, the frequency of the sound wave generally remains constant and does not routinely change as the sound propagates through the body. Slight changes in frequency occur when sound strikes moving structures. This forms the basis for Doppler ultrasonography.</p> |
| <p>60. When a sonographer increases the maximum imaging depth during an exam, what happens to the frequency?</p> <p>A. frequency increases<br/>           B. frequency decreases<br/>           C. remains unchanged</p>                  | <p>C. Imaging depth and frequency are unrelated. When the depth of view is increased, the frequency of sound remains the same.</p>                                                                                                                                                                       |
| <p>61. Ultrasound is defined as a sound with a frequency of ____.</p> <p>A. greater than 20,000 kHz<br/>           B. less than 1 kHz<br/>           C. greater than 10 MHz<br/>           D. greater than 0.02 MHz</p>                   | <p>D. Ultrasound is defined as an acoustic wave with a frequency so high that it is not audible to humans. Ultrasound is an inaudible wave with a frequency of at least 20,000 Hz, 20 kHz or 0.02 MHz.</p>                                                                                               |



| Questions                                                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                        |
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| <p>62. Infrasound is defined as a sound with a frequency of ____.</p> <ul style="list-style-type: none"> <li>A. greater than 20,000 kHz</li> <li>B. less than 20 Hz</li> <li>C. greater than 10 MHz</li> <li>D. less than 0.02 MHz</li> </ul>                                                                                                                                                       | <p><b>B.</b> Infrasound is defined as an acoustic wave with a frequency so low that it is not audible to humans. Infrasound is an inaudible wave with a frequency of less than 20 Hz.</p>                                                                                      |
| <p>63. True or False? Waves in the ultrasound range behave in the same general manner as sound waves that are audible.</p>                                                                                                                                                                                                                                                                          | <p><b>True.</b> As stated above, the primary difference between audible and ultrasonic waves is that humans can hear audible waves. A wave's behavior or adherence to physical laws and principles is generally the same, regardless of whether it can be heard by humans.</p> |
| <p>64. What is characteristic of acoustic waves with frequencies exceeding 20,000 Hz when compared with waves having frequencies of less than 20,000 Hz?</p> <ul style="list-style-type: none"> <li>A. they travel more effectively in soft tissue</li> <li>B. they travel more rapidly</li> <li>C. they attenuate less when traveling in soft tissue</li> <li>D. humans can't hear them</li> </ul> | <p><b>D.</b> Waves with frequencies exceeding 20 kHz are inaudible to humans and are called ultrasonic. They travel at the same speed as waves with lower frequencies and attenuate at a faster rate than waves with lower frequencies.</p>                                    |
| <p>65. What is characteristic of acoustic waves with frequencies of less than 20 Hz when compared with waves having frequencies of more than 20 Hz?</p> <ul style="list-style-type: none"> <li>A. they travel less effectively in soft tissue</li> <li>B. they travel more rapidly</li> <li>C. they attenuate more when traveling in soft tissue</li> <li>D. humans can't hear them</li> </ul>      | <p><b>D.</b> Waves with frequencies of less than 20 Hz are inaudible to humans and are called infrasonic. They travel at the same speed as waves with higher frequencies and attenuate at a lesser rate than waves at higher frequencies.</p>                                  |

| Questions                                                                                                                                                                                                                                                                                                | Answers                                                                                                                                                                                                                                                                                                                                                                |
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| <p>66. The frequency of a continuous acoustic wave is 5 MHz. The wave is then pulsed with a duty factor of 0.1. What is the new frequency?</p> <p>A. 0.5<br/>B. 0.5 MHz<br/>C. 5 MHz<br/>D. 10 MHz</p>                                                                                                   | <p>C. Frequency is the reciprocal of the period. The fact that a wave is pulsed rather than continuous does not alter the frequency of the signal. The new and old frequencies are the same, 5 million/second.</p>                                                                                                                                                     |
| <p>67. True or False? The period of an ultrasound wave is related to the frequency and is the same, regardless of whether the wave is pulsed or continuous.</p>                                                                                                                                          | <p><b>True.</b> The period of a wave is a characteristic of each individual cycle in the wave. The period of a wave (as well as frequency and wavelength) remains unchanged, whether the wave is continuous or pulsed.</p>                                                                                                                                             |
| <p>68. True or False? If the periods of two waves are the same, then the frequencies of the waves must also be the same.</p>                                                                                                                                                                             | <p><b>True.</b> Frequency and period are reciprocals. When the periods of two waves are identical, the frequencies of the waves must also be identical.</p>                                                                                                                                                                                                            |
| <p>69. Compare two sound waves, A and B. The frequency of wave A is one-third that of wave B. How does the period of wave A compare with the period of wave B?</p> <p>A. A is one-third as long as B<br/>B. A is the same as wave B<br/>C. A is three times as long as B<br/>D. cannot be determined</p> | <p>C. Frequency and period are reciprocals. If the frequency of one wave is one-third as large as another, then the period of the wave will be three times longer than the other.</p>                                                                                                                                                                                  |
| <p>70. _____ is the reciprocal of period.</p> <p>A. inverse period<br/>B. pulse repetition period<br/>C. frequency<br/>D. propagation period</p>                                                                                                                                                         | <p>C. Frequency is the reciprocal of period. Reciprocals are related in two ways:</p> <ul style="list-style-type: none"> <li>• As one increases, the other decreases.</li> <li>• When they are multiplied together, the result is unity.</li> </ul> <p>For example, a wave with a period of one-hundredth of a second has a frequency of 100 per second or 100 Hz.</p> |

## Questions

## Answers

**AMPLITUDE, POWER, and INTENSITY**

- |                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                |
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| <p>71. What determines the initial amplitude of an ultrasound wave?</p> <p>A. the transducer<br/>B. the medium through which the sound travels<br/>C. both A and B<br/>D. neither choice A nor B</p> | <p><b>A.</b> The initial strength or amplitude of a sound wave is determined by the vibration of the piezoelectric crystal in the transducer. The greater the vibration of the crystal, the larger the amplitude of the ultrasound wave.</p>                                                                                                                   |
| <p>72. True or False? With standard diagnostic imaging instrumentation, the sonographer has the ability to vary the amplitude of a sound wave produced by the transducer.</p>                        | <p><b>True.</b> The sonographer can adjust the strength of the ultrasound signal that a transducer creates. When a sonographer increases the output power, the electrical voltage sent to the transducer is increased. This produces a more violent vibration of the piezoelectric crystal within the transducer and, in turn, a stronger ultrasound wave.</p> |
| <p>73. As an ultrasound wave travels through the body, its amplitude usually:</p> <p>A. decreases<br/>B. increases<br/>C. remains the same<br/>D. cannot be determined</p>                           | <p><b>A.</b> As a sound wave travels in the body, its strength or amplitude diminishes. This process is called attenuation. We experience attenuation when walking away from a person who is speaking. The further away we are from a speaker, the weaker that person's voice becomes.</p>                                                                     |
| <p>74. Which of the following are acceptable units for the amplitude of an acoustic wave? (More than one answer may be correct.)</p> <p>A. cm<br/>B. pascals<br/>C. gauss<br/>D. watts</p>           | <p><b>A and B.</b><br/>The acoustic variables are pressure, density, and particle motion. The units of acoustic wave amplitude are cm for particle motion and pascals for pressure.</p>                                                                                                                                                                        |

Amplitude  
 pressure Pa  
 density kg/cm<sup>3</sup>  
 distance cm, m



| Questions                                                                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                                                                                                   |
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| <p>75. The maximum value of the density of an acoustic wave is <math>60 \text{ lb/in}^2</math> while the minimum density is <math>20 \text{ lb/in}^2</math>. What is the amplitude of the wave?</p> <p>A. <math>20 \text{ lb/in}^2</math><br/>         B. <math>40 \text{ lb/in}^2</math><br/>         C. <math>60 \text{ lb/in}^2</math><br/>         D. none of the above</p> | <p>A. To calculate the amplitude of a wave, subtract the minimum value of the acoustic variable from its maximum and then divide that number in half. In this case, the maximum minus the minimum is <math>60 - 20 = 40 \text{ lb/in}^2</math>.</p> <p>Half of 40 is <math>20 \text{ lb/in}^2</math>.</p> |
| <p>76. The power of an ultrasound wave can be reported with which of the following units? (More than one answer may be correct.)</p> <p>A. watts/square centimeter<br/>         B. dB/cm<br/>         C. watts<br/>         D. <math>\text{kg/cm}^2</math></p>                                                                                                                  | <p>C. The units of power are watts. This is the same measure of power as for light bulbs, stereo systems, and curling irons.</p>                                                                                                                                                                          |
| <p>77. Typically, as an ultrasound wave travels through soft tissue, the power of the wave:</p> <p>A. decreases<br/>         B. increases<br/>         C. remains the same</p>                                                                                                                                                                                                  | <p>A. As a sound wave travels through the body, its power diminishes. This process is called attenuation. Amplitude and power are both measures of the strength of an acoustic wave, and tend to decrease as sound travels.</p>                                                                           |
| <p>78. True or False? A sonographer can routinely change the power of a wave emitted by a transducer used in diagnostic ultrasonic imaging.</p>                                                                                                                                                                                                                                 | <p>True. A sonographer can alter the power of an ultrasound wave by adjusting a control on the ultrasound system. Power and amplitude are related; if the amplitude is increased, then so is the power. When the amplitude decreases, the power also decreases.</p>                                       |
| <p>79. Mathematically, when a number is squared, the number is multiplied by:</p> <p>A. 2<br/>         B. 0.5<br/>         C. itself<br/>         D. 1.5</p>                                                                                                                                                                                                                    | <p>C. To square a number means to multiply the number by itself. Hence, the term "five squared" means 5 times 5, or 25. Ten squared is 10 times 10, or 100.</p>                                                                                                                                           |

| Questions                                                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                                                                                                                                                                                      |
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| <p>80. The final amplitude of an acoustic wave is reduced to one-half of its original value. The final power is ____ the original power.</p> <p>A. the same as<br/>B. one-half<br/>C. double<br/>D. none of the above</p>                                   | <p>D. Changes in the power of a wave are proportional to changes in the wave's amplitude squared. One-half squared equals one-quarter (<math>1/2 \times 1/2 = 1/4</math>). When one-half of the wave's original amplitude remains, then only one-fourth of the original power remains.</p>                                                                                   |
| <p>81. The amplitude of an acoustic wave decreases from 27 pascals to 9 pascals. If the initial power in the wave was 27 watts, what is the wave's final power?</p> <p>A. 3 watts<br/>B. 9 watts<br/>C. 1 watt<br/>D. none of the above</p>                 | <p>A. Alterations in a wave's power are proportional to changes in its amplitude squared. The power is reduced to one-third of its previous value (from 27 to 9 pascals). One-third squared equals one-ninth. Thus, only one-ninth of the wave's original power remains. The initial power in the wave was 27 watts, one-ninth of that is <math>27/9</math>, or 3 watts.</p> |
| <p>82. The intensity of an ultrasound beam is defined as the ____ in a beam ____ by the ____ of the beam.</p> <p>A. power, multiplied, diameter<br/>B. amplitude, divided, area<br/>C. power, divided, area<br/>D. amplitude, multiplied, circumference</p> | <p>C. The intensity of an ultrasound beam is the concentration of the power within the beam area. It is calculated by dividing the power in a beam by its area. The units of intensity are watts per centimeter squared, <math>w/cm^2</math>.</p>                                                                                                                            |
| <p>83. As sound travels in the body, what typically happens to the intensity of the wave?</p> <p>A. increases<br/>B. decreases<br/>C. remains the same</p>                                                                                                  | <p>B. The intensity of a sound beam decreases as it travels through the body because of attenuation. Amplitude, power, and intensity are three different ways to measure the strength of an ultrasound beam. They all decrease as sound propagates.</p>                                                                                                                      |
| <p>84. What are the units of intensity?</p> <p>A. watts<br/>B. watts/cm<br/>C. watts/cm<sup>2</sup><br/>D. dB</p>                                                                                                                                           | <p>C. The intensity of a beam is the power in the beam divided by its cross-sectional area. Power has units of watts and beam area has units of square cm. Intensity has units of watts/cm<sup>2</sup>.</p>                                                                                                                                                                  |

| Questions                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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| <p>85. True or False? With diagnostic ultrasonic imaging instruments, the operator can alter the intensity of an ultrasound beam produced by a transducer.</p>                                                                        | <p><b>True.</b> Although operators cannot change all the characteristics of an ultrasound beam produced by an individual transducer, they can change the initial power. As the operator increases the output power of a transducer, the initial intensity increases.</p>                                                                                                                                                                                                                                                                                                                                               |
| <p>86. What determines the initial intensity of an ultrasound beam?</p> <p>A. the source of the sound wave<br/>B. the medium through which the sound travels<br/>C. both A and B<br/>D. neither A nor B</p>                           | <p><b>A.</b> The source of the acoustic wave determines the initial intensity (as well as the wave's amplitude and power). At its point of origin, the strength of an acoustic wave will not be related to the medium that the sound is about to enter.</p>                                                                                                                                                                                                                                                                                                                                                            |
| <p>87. What determines the intensity of an ultrasound beam after it has traveled through the body?</p> <p>A. the sound wave's source<br/>B. the medium through which the sound travels<br/>C. both A and B<br/>D. neither A nor B</p> | <p><b>C.</b> The source and the medium both ultimately determine the residual intensity of an ultrasound beam after it passes through the body. Sound waves attenuate as they propagate. The initial intensity of a sound beam is established by the source of the sound, the transducer. The frequency, which is also determined by the transducer, affects the rate of attenuation. In addition, the characteristics of the medium help to determine attenuation. For example, bone and lung have a greater attenuation rate than soft tissue. In contrast, water has a lower attenuation rate than soft tissue.</p> |
| <p>88. What are the units of the transmitted intensity of a sound wave?</p> <p>A. <math>\text{W/cm}^2</math><br/>B. watts<br/>C. dB<br/>D. none; it is unitless</p>                                                                   | <p><b>A.</b> As sound propagates, one of the ways to measure its strength is to record its intensity. The intensity of the part of a beam that continues to propagate in the forward direction as it reaches a boundary is called the transmitted intensity. It is reported in units <math>\text{w/cm}^2</math>.</p>                                                                                                                                                                                                                                                                                                   |



| Questions                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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| <p>89. What happens when the power in an ultrasound beam is unchanged, and at the same time, the beam area doubles?</p> <p>A. doubles<br/>B. is halved<br/>C. is quartered<br/>D. remains the same</p>                                                                                                            | <p>B. Intensity is equal to power divided by beam area. In this case, the power is unchanged while the beam area is doubled. Therefore, the beam's intensity is halved. For example, if the original power was 2 watts and the initial beam area was <math>2 \text{ cm}^2</math>, then the starting intensity was 2 watts divided by <math>2 \text{ cm}^2</math>, or <math>1 \text{ watt/cm}^2</math>. Now, beam area is doubled, from 2 to <math>4 \text{ cm}^2</math>. The new intensity is 2 watts divided by <math>4 \text{ cm}^2</math> or <math>0.5 \text{ watts/cm}^2</math>. The initial intensity was 1, and the final intensity is <math>0.5 \text{ watts/cm}^2</math>; therefore, the intensity has been halved.</p>                                              |
| <p>90. What happens to an acoustic beam's intensity when the power in the beam increases by 25% while the cross-sectional area of the beam remains the same?</p> <p>A. it increases by 25%<br/>B. increases by 75%<br/>C. it increases by 50%<br/>D. decreases by 25%</p>                                         | <p>A. The intensity is equal to the power divided by the beam area. If the power increases by 25% while the beam's area is unchanged, then the intensity is also increased by 25%.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <p>91. When the power in an acoustic beam is doubled and the cross-sectional area of the beam is halved, then the intensity of the beam is:</p> <p>A. doubled<br/>B. halved<br/>C. quartered<br/>D. four times larger</p> <p style="text-align: center;"><math>\frac{2 \rightarrow 4}{4 \rightarrow 2}</math></p> | <p>D. The intensity rises to four times its original value. Intensity is equal to power divided by beam area. In this case, the power is doubled and the area is halved. For example, if the original power was 4 watts and the initial beam area was <math>4 \text{ cm}^2</math>, then the starting intensity was 4 watts divided by <math>4 \text{ cm}^2</math>, or <math>1 \text{ watt/cm}^2</math>. Now, the power is doubled from 4 to 8 watts and the beam area is halved, from 4 to <math>2 \text{ cm}^2</math>. The new intensity is 8 watts divided by <math>2 \text{ cm}^2</math>, or <math>4 \text{ watts/cm}^2</math>. Since the initial intensity was 1 and the final intensity is <math>4 \text{ watts/cm}^2</math>, the intensity has increased fourfold.</p> |

$$\frac{1}{2} \rightarrow 2$$

$$\frac{4}{4} = \frac{8}{2} = 4$$

| Questions                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                               |
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| <p>92. What happens to the intensity of an ultrasound beam when the beam's cross-sectional area remains unchanged while the amplitude of the wave triples?</p> <p>A. it triples<br/>B. increases ninefold<br/>C. remains the same<br/>D. none of the above</p>  | <p>B. A change in the intensity of a wave is proportional to the change in the amplitude of the wave squared. When the amplitude of a wave is tripled, the intensity is increased ninefold (<math>3 \times 3 = 9</math>).</p>                                                                                                         |
| <p>93. If the power of the beam is tripled while the cross-sectional area of the beam remains the same, the intensity ____.</p> <p>A. triples<br/>B. increases ninefold<br/>C. remains the same<br/>D. none of the above</p>                                                                                                                     | <p>A. When the cross-sectional area of a beam remains unchanged, the change in the intensity of a beam is proportional to the change in the power. The question states that the power is tripled. If the power is tripled, then the intensity is also tripled.</p>                                                                    |
| <p>94. The amplitude of an acoustic wave is increased. Which of the following will most likely remain unchanged? (More than one answer may be correct.)</p> <p>A. power<br/>B. frequency<br/>C. period<br/>D. intensity</p>                                                                                                                      | <p>B and C.</p> <p>Amplitude relates to the strength of a wave. The frequency of a wave describes the number of cycles in one second. A wave's period is the time an acoustic variable oscillates through one complete cycle. Frequency and period are not related to amplitude, and remain unaltered when the amplitude changes.</p> |
| <p>95. A sonographer adjusts the output power of the wave emitted by the transducer. Which of the following also changes? (More than one answer may be correct.)</p> <p>A. pulse repetition period<br/>B. PRF<br/>C. propagation speed<br/>D. intensity</p>                                                                                      | <p>D. As a sonographer adjusts the output power, the intensity will change.</p> <p>The PRF and pulse repetition period will change only when the maximum imaging depth (also called depth of view) changes. The sound's propagation speed will change only if the medium changes.</p>                                                 |

| Questions                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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| <b>WAVELENGTH</b>                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <p>96. The wavelength of a cycle in an ultrasound wave can be reported with which units?</p> <p>A. units of time (sec, min, etc.)<br/>           B. units of distance (feet, etc.)<br/>           C. units of area (<math>m^2</math>, etc.)<br/>           D. mm only</p> | <p><b>B.</b> Wavelength is the <i>distance</i> from the beginning to the end of one cycle. It has units of distance. In soft tissue, and with frequencies typical of diagnostic imaging, wavelengths range from 0.15 to 0.75 mm. Although it may be impractical to record wavelengths in miles or meters, it can be done since they are distances.</p>                                                                                                                               |
| <p>97. The wavelength of an ultrasonic wave is determined by:</p> <p>A. the sound source<br/>           B. the medium through which the wave travels<br/>           C. both A and B<br/>           D. neither A nor B</p>                                                 | <p><b>C.</b> Wavelength is determined by both the sound source and the medium through which it travels. Wavelength is determined, in part, by the wave's frequency (which is established by the sound source). Wavelength is also affected by the speed of the sound wave, which is established by the medium.</p> <p>In a particular medium, higher frequency waves have shorter wavelengths. With a particular frequency, faster propagation speeds create longer wavelengths.</p> |
| <p>98. What is the wavelength of 2 MHz sound in soft tissue?</p> <p>A. 0.77 mm<br/>           B. cannot be determined<br/>           C. 1.54 mm<br/>           D. 2 mm</p>                                                                                                | <p><b>A.</b> The wavelength of sound in soft tissue is defined by the following relationship:<br/> <math>\text{wavelength (mm)} = 1.54 / \text{frequency (MHz)}</math><br/>           For 2 MHz sound, the wavelength is <math>1.54/2</math> or 0.77 mm.</p>                                                                                                                                                                                                                         |
| <p>99. Which of the following terms best describes the relationship between frequency and wavelength for sound traveling in soft tissue?</p> <p>A. reciprocal<br/>           B. direct<br/>           C. related<br/>           D. inverse</p>                            | <p><b>D.</b> The relationship between frequency and wavelength is inverse. Higher frequency waves are related to shorter wavelengths. Lower frequency waves are related to longer wavelengths.</p>                                                                                                                                                                                                                                                                                   |



| Questions                                                                                                                                                  | Answers                                                                                                                                                                                                                                                                                                                            |
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| Two sound pulses travel through the same medium. One wave's frequency is 2 MHz and the other is 10 MHz. Answer the following 5 questions.                  |                                                                                                                                                                                                                                                                                                                                    |
| <p>100. Which sound wave has a longer period?</p> <p>A. the 10 MHz pulse<br/>B. the 2 MHz pulse<br/>C. neither pulse<br/>D. cannot be determined</p>       | <p><b>B.</b> Frequency and period are reciprocals. The wave with a higher frequency has a shorter period. Lower frequencies have longer periods. The 2 MHz wave has a period five times longer than the 10 MHz wave.</p>                                                                                                           |
| <p>101. Which pulse has a longer wavelength?</p> <p>A. the 10 MHz pulse<br/>B. the 2 MHz pulse<br/>C. neither pulse<br/>D. cannot be determined</p>        | <p><b>B.</b> In any specific medium, the wave with the lower frequency has the longer wavelength. The 2 MHz sound's wavelength is five times longer than the 10 MHz wave.</p>                                                                                                                                                      |
| <p>102. Which pulse has a lower propagation speed?</p> <p>A. the 10 MHz pulse<br/>B. the 2 MHz pulse<br/>C. neither pulse<br/>D. cannot be determined</p>  | <p><b>C.</b> The propagation speeds of all sound waves are identical while traveling in a specific medium.</p>                                                                                                                                                                                                                     |
| <p>103. Which pulse has the lowest power?</p> <p>A. the 10 MHz pulse<br/>B. the 2 MHz pulse<br/>C. neither pulse<br/>D. cannot be determined</p>           | <p><b>D.</b> The power of a wave is not related to its frequency. The power relates to the strength of the wave, and in this case, no information is provided about the power. Therefore, we cannot answer this question based on the information provided.</p>                                                                    |
| <p>104. Which pulse has a longer spatial pulse length?</p> <p>A. the 10 MHz wave<br/>B. the 2 MHz wave<br/>C. neither wave<br/>D. cannot be determined</p> | <p><b>D.</b> The spatial pulse length is equal to the wavelength multiplied by the number of cycles in the pulse. We know that 2 MHz sound has a longer wavelength than 10 MHz ultrasound. However, the number of cycles that comprise each pulse is unknown. The information provided is insufficient to answer the question.</p> |
| <p>105. True or False? Lower frequency sound creates higher quality images with greater detail.</p>                                                        | <p><b>False.</b> Frequency plays a very important role in image quality. Higher frequency sound usually produces higher quality images with greater detail.</p>                                                                                                                                                                    |

| Questions                                                                                                                                     | Answers                                                                                                                                                                                                                                                                                                                                                                        |
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| <p>106. What is the wavelength of 10 MHz sound in soft tissue?</p> <p>A. 0.77 mm<br/>B. 0.15 mm<br/>C. 1.54 mm<br/>D. 10 mm</p>               | <p><b>B.</b> The wavelength of sound in soft tissue is defined by the following relationship:</p> <p>wavelength (mm) = 1.54 / frequency (MHz)</p> <p>For 2 MHz sound, the wavelength is 1.54/10 or 0.15 mm.</p>                                                                                                                                                                |
| <p>Two waves, a 5 MHz ultrasonic wave and a 5 kHz audible wave, travel through soft tissue. Are the following 4 statements true or false?</p> |                                                                                                                                                                                                                                                                                                                                                                                |
| <p>107. The period of the 5 MHz wave is less than the period of the audible wave.</p>                                                         | <p><b>True.</b> The period and frequency of any wave are inversely proportional. That is, the higher the frequency of wave, the shorter the period. In this case, the 5 MHz wave has a higher frequency than the 5 kHz wave and, thus, will have a shorter period.</p>                                                                                                         |
| <p>108. The wavelength of the 5 MHz wave is greater than the wavelength of the 5 kHz wave.</p>                                                | <p><b>False.</b> When two sound waves travel through the same medium, the higher frequency wave has a shorter wavelength. The wave with the lower frequency has a longer wavelength. In this question, the 5 MHz wave has a higher frequency and therefore has a shorter wavelength. Specifically, the wavelength of the 5 kHz wave is 1,000 times that of the 5 MHz wave.</p> |
| <p>109. The ultrasound wave travels much faster than the audible wave.</p>                                                                    | <p><b>False.</b> All sound waves, regardless of their frequencies, travel at exactly the same speed in a particular medium. Both waves propagate at the same speed. In soft tissue, sound propagates at a speed of 1,540 m/sec.</p>                                                                                                                                            |
| <p>110. Both the 5 MHz and the 5 kHz waves travel at similar speeds through the medium.</p>                                                   | <p><b>True.</b> All sound waves travel at exactly the same speed while moving through a particular medium.</p>                                                                                                                                                                                                                                                                 |

| Questions                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                          |
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| <b>PROPAGATION SPEED</b>                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                  |
| An ultrasound pulse propagates from soft tissue through a mass. Sound's propagation speed in the mass is 1,575 m/s. Are these 4 statements true or false?                                                                             |                                                                                                                                                                                                                                                                                                                                  |
| 111. The frequency of the wave increases as it travels through the mass.                                                                                                                                                              | <b>False.</b> A wave's frequency is determined by the sound source only, and is unaffected by the tissues through which it travels.                                                                                                                                                                                              |
| 112. The period of the sound wave decreases as it travels through the mass.                                                                                                                                                           | <b>False.</b> The period of a wave is determined by the sound source only, and is unaffected by the tissues through which it travels.<br><br>Recall that period and frequency are reciprocals. Since the frequency remained unchanged, so too must the period.                                                                   |
| 113. The wavelength increases while the wave travels through the mass.                                                                                                                                                                | <b>True.</b> Wavelength is dependent on both the sound source and the medium. The speed of sound in soft tissue is 1,540 m/sec, and through the mass is 1,575 m/sec. As a wave travels in a faster medium, its wavelength increases.                                                                                             |
| 114. The power in the wave increases as it travels through the mass.                                                                                                                                                                  | <b>False.</b> Typically, the power of a beam diminishes as it travels. This is a result of attenuation. If anything, the wave's power diminishes as it propagates through the mass.                                                                                                                                              |
| Three sound waves with identical frequencies of 3 MHz have powers of 2 mW, 5 mW and 15 mW. They all travel through three media—wood, brick, and fat—with identical thicknesses of 5 cm. Are the following 3 statements true or false? |                                                                                                                                                                                                                                                                                                                                  |
| 115. The waves travel through all three media at the same speed since they have identical frequencies.                                                                                                                                | <b>False.</b> The determinant of the propagation speed in a medium is the medium only. The fact that these three waves have the same frequency is irrelevant. The waves are traveling in media with vastly different densities and stiffnesses and as a result will travel at different speeds through the wood, brick, and fat. |



| Questions                                                                                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                             |
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| <p>116. The sound waves travel through all three media at different speeds because the waves have different powers.</p>                                                                                                                                                                                                                                   | <p><b>False.</b> The fact that the waves have dissimilar powers is not the reason they travel at different speeds. The waves travel at different speeds because of the dissimilarities in the densities and stiffnesses of the media through which they travel.</p> |
| <p>117. The waves travel through all three media at different speeds because the media are different.</p>                                                                                                                                                                                                                                                 | <p><b>True.</b> This is correct! Finally, we have a statement that attributes variations in propagation speeds to the differences in the media. Again, the characteristics of the media alone determine the speed that sound can travel through it.</p>             |
| <p>118. Propagation speed can be correctly recorded with which of the following units? (More than one may be correct.)</p> <ul style="list-style-type: none"> <li>A. miles per hour</li> <li>B. mm/msec</li> <li>C. km/sec</li> <li>D. inches per year</li> </ul>                                                                                         | <p><b>A, B, C, and D.</b><br/>Speed is recorded as a distance per unit of time, such as miles per hour, or feet/sec. Any relationship of distance per time is an acceptable answer.</p>                                                                             |
| <p>119. The propagation speed of continuous wave ultrasound is 1.8 kilometers per second. The wave is then pulsed with a duty factor of 50%. What is the new propagation speed?</p> <ul style="list-style-type: none"> <li>A. 0.5 km/sec</li> <li>B. 0.9 km/sec</li> <li>C. 1.8 km/sec</li> <li>D. 3.6 km/sec</li> <li>E. cannot be determined</li> </ul> | <p><b>C.</b> The speed of sound in a medium is determined only by the medium. There is no difference in sound's speed whether the wave is continuous or pulsed. Thus, the new and old speeds will be identical, 1.8 km/sec.</p>                                     |
| <p>120. What is the best estimate of the distance that sound can travel in soft tissue in one second?</p> <ul style="list-style-type: none"> <li>A. one yard</li> <li>B. one hundred yards</li> <li>C. one mile</li> <li>D. ten miles</li> </ul>                                                                                                          | <p><b>C.</b> Sound travels at a speed of 1,540 meters per second in soft tissue. This is approximately one mile per second.</p>                                                                                                                                     |

| Questions                                                                                                                                                                                                 | Answers                                                                                                                                                                                |
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| 121. True or False? Shorter wavelength sound creates higher quality images with greater detail.                                                                                                           | <b>True.</b> Wavelength plays a very important role in image quality. Shorter wavelength (higher frequency sound) produces higher quality images with greater detail.                  |
| 122. True or False? The wavelength of an acoustic wave is shorter when it is pulsed rather than continuous.                                                                                               | <b>False.</b> Wavelength reports the length of one cycle in a wave. The wavelength does not change based on whether the cycle is part of a pulsed or continuous wave.                  |
| 123. The speed of sound traveling through bone is ____ soft tissue.<br>A. higher than<br>B. lower than<br>C. equal to<br>D. cannot be determined                                                          | <b>A.</b> The propagation speed of sound in bone is higher than in soft tissue. Sound travels at a speed of 3 to 5 km/sec in bone. This is two to three times faster than soft tissue. |
| 124. Compared to soft tissue, the speed of an acoustic wave through lung tissue is ____.<br>A. faster<br>B. slower<br>C. equal<br>D. cannot be determined                                                 | <b>B.</b> The speed of sound in lung tissue is slower than in soft tissue. Sound travels at speeds in the range of 0.5 to 1.0 km/sec in lung tissue.                                   |
| 125. What is the best estimate for the speed of sound in tendon?<br>A. 1,000 m/s<br>B. 1,540 m/s<br>C. 1,754 m/s<br>D. 5,400 m/s                                                                          | <b>C.</b> Sound travels slightly faster in tendon than in soft tissue.                                                                                                                 |
| 126. As a general rule, which of the following lists media in increasing order of propagation speeds?<br>A. gas, solid, liquid<br>B. liquid, solid, gas<br>C. solid, liquid, gas<br>D. gas, liquid, solid | <b>D.</b> Generally, sound travels slowest in gases, faster in liquids, and fastest in solids.                                                                                         |

| Questions                                                                                                                                                                                 | Answers                                                                                                                                                                                                                          |
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| <p>127. What is the speed of sound in air?</p> <p>A. 1,540 m/s<br/>B. 330 m/s<br/>C. 100 m/s<br/>D. 3,010 m/s</p>                                                                         | <p><b>B.</b> The speed of sound in air is 330 m/s, substantially lower than the speed of sound in soft tissue.</p>                                                                                                               |
| <p>128. True or False? Soft tissue is an imaginary construct that actually does not exist.</p>                                                                                            | <p><b>True.</b> Soft tissue is an imaginary structure with characteristics that represent an "average" of body tissues, including muscle, blood, kidney, and spleen. It is used as an approximation.</p>                         |
| <p>129. What is the propagation speed of a 5 megahertz sound wave in soft tissue?</p> <p>A. 1,450 meters per sec<br/>B. 1,540 km/sec<br/>C. 1.54 m/s<br/>D. 1.54 mm/<math>\mu</math>s</p> | <p><b>D.</b> The speed of any sound wave moving through soft tissue, regardless of frequency, is 1.54 mm/<math>\mu</math>sec, 1,540 m/sec, or 1.54 km/sec.</p>                                                                   |
| <p>130. If sound travels at exactly 1,540 m/sec in a particular medium, then the medium ____.</p> <p>A. must be soft tissue<br/>B. may be soft tissue<br/>C. cannot be soft tissue</p>    | <p><b>B.</b> Sound waves travel exactly 1,540 m/sec in soft tissue. However, other media have the same propagation speed as that of soft tissue. The medium in question could be soft tissue, or it could be something else.</p> |
| <p>131. If sound doesn't travel at 1,540 m/sec in a medium, then the medium ____.</p> <p>A. must be soft tissue<br/>B. may be soft tissue<br/>C. cannot be soft tissue</p>                | <p><b>C.</b> Sound waves travel exactly 1,540 m/sec in soft tissue. Since the propagation speed of sound in this medium is not 1,540 m/sec, the medium cannot be soft tissue.</p>                                                |
| <p>132. The propagation speeds of ultrasound waves in muscle, liver, kidney, and blood are ____.</p> <p>A. exactly the same<br/>B. very similar to each other<br/>C. vastly different</p> | <p><b>B.</b> The speed of sound in these media are less than 5% different from each other. The characteristics of muscle, kidney, liver, and blood that determine the wave's speed in the media are quite similar.</p>           |



| Questions                                                                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                                                                      |
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| <p>133. The speed at which a wave travels through a medium is determined by:</p> <ul style="list-style-type: none"> <li>A. the sound wave's properties only</li> <li>B. the medium's properties only</li> <li>C. properties of both wave and medium</li> <li>D. none of the above</li> </ul>                                                          | <p><b>B.</b> Speed is determined by the characteristics of the medium only. The characteristics of the wave do not affect its speed. All sound waves of any frequency, period, intensity, and power travel at the same speed in a particular medium.</p>                                                                                                                     |
| <p>134. What two properties establish sound's propagation speed in a given medium?</p> <ul style="list-style-type: none"> <li>A. elasticity and stiffness</li> <li>B. stiffness and impedance</li> <li>C. conductance and density</li> <li><b>D. density and stiffness</b></li> </ul>                                                                 | <p><b>D.</b> The two properties of the medium that affect sound's propagation speed are density and stiffness.</p>                                                                                                                                                                                                                                                           |
| <p>135. The characteristics of four media are described below. Which of the media has the slowest propagation speed?</p> <ul style="list-style-type: none"> <li>A. high density and high elasticity</li> <li>B. low density and high stiffness</li> <li>C. low stiffness and low density</li> <li>D. low compressibility and low stiffness</li> </ul> | <p><b>A.</b> Speed is determined by density and stiffness of a medium (the opposite of stiffness is elasticity). When a medium has high elasticity, its speed is slow. A medium with a high density also has a slow speed. The medium described in choice A has the lowest propagation speed.</p>                                                                            |
| <p>136. Compressibility describes a characteristic of a medium. Which two terms describe the same property as compressibility?</p> <ul style="list-style-type: none"> <li>A. density and stiffness</li> <li>B. density and conductance</li> <li>C. stiffness and elasticity</li> <li>D. elastance and impedance</li> </ul>                            | <p><b>C.</b> The compressibility of a medium describes its ability to reduce its volume when a force is applied to it. For example, a marshmallow is compressible because when it is squeezed, it gets smaller. Elasticity has the same meaning as compressibility. Stiffness describes this same characteristic; however, stiffness is the opposite of compressibility.</p> |
| <p>137. When the elasticity of a medium is high, the ____ is high.</p> <ul style="list-style-type: none"> <li>A. stiffness</li> <li>B. propagation speed</li> <li>C. compressibility</li> <li>D. reflectivity</li> </ul>                                                                                                                              | <p><b>C.</b> Both elasticity and compressibility describe the ability of a medium to reduce its volume when affected by a force. High elasticity means the same as high compressibility.</p>                                                                                                                                                                                 |

| Questions                                                                                                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                                                                                                         |
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| <p>138. Two sound waves with frequencies of 5 and 3 MHz travel to a depth of 8 cm in a medium and then reflect back to the surface of the body. Which acoustic wave arrives first at the surface of the body?</p> <p>A. the 5 MHz wave<br/>B. the 3 MHz wave<br/>C. neither<br/>D. cannot be determined</p> | <p>C. They both travel at the same speed and reach the surface of the body at exactly the same time. <i>All sound waves, regardless of their features, travel at the same speed in a specific medium.</i> The fact that these waves have different frequencies is irrelevant.</p>               |
| <b>PULSED ULTRASOUND</b>                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                 |
| <p>139. What are the units of pulse duration?</p> <p>A. units of frequency (Hz, etc.)<br/>B. msec only<br/>C. units of time (sec, years, etc.)<br/>D. units of distance (feet, etc.)</p>                                                                                                                    | <p>C. The pulse duration is the actual time that a transducer is creating one pulse. Hence, it has units of time. The typical range of pulse durations found in diagnostic imaging equipment is 0.3 to 2 <math>\mu</math>sec, but it is valid to report pulse duration in any unit of time.</p> |
| <p>140. What determines the pulse duration?</p> <p>A. the source of the wave<br/>B. the medium in which the pulse travels<br/>C. both A and B<br/>D. neither A nor B</p>                                                                                                                                    | <p>A. The pulse duration is the actual time that a transducer is creating one sound pulse and is determined by the ultrasound system. Pulse duration does not include the listening time.</p>                                                                                                   |
| <p>141. True or False? The pulse duration of an ultrasound and transducer system does not change significantly as long as the system components remain unchanged.</p>                                                                                                                                       | <p><b>True.</b> The pulse duration is the timespan that a pulse exists. It is determined by the ultrasound system and the transducer. Generally, it remains constant for a particular transducer.</p>                                                                                           |
| <p>142. The pulse duration is expressed in the same units as the ____.</p> <p>A. period<br/>B. PRF<br/>C. wavelength<br/>D. density</p>                                                                                                                                                                     | <p>A. The pulse duration and the period are measured in units of time, such as seconds, minutes, or hours.<br/><br/>PRF has units of hertz. Wavelength has units of distance. Density has units of mass per volume.</p>                                                                         |

| Questions                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                    |
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| Are the following 4 statements regarding pulse duration true or false?                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                            |
| 143. A sonographer can adjust the duration of an acoustic pulse since it depends upon the pulse's propagation speed.                                                                                                                                | <b>False.</b> A sonographer cannot change the pulse duration. It is a fixed feature of the transducer and ultrasound system. It does not depend upon propagation speed.                                                                                                                                                                                                                    |
| 144. A sonographer can adjust the duration of an acoustic pulse since it depends upon the maximum imaging depth.                                                                                                                                    | <b>False.</b> A sonographer cannot change the pulse duration. It has a constant value, and is not dependent on imaging depth.                                                                                                                                                                                                                                                              |
| 145. The sonographer cannot change the duration of a sound pulse unless the transducers are switched.                                                                                                                                               | <b>True.</b> The pulse duration depends upon the interaction of the pulser electronics of the machine and the transducer. The pulse duration may change when the sonographer changes transducers.                                                                                                                                                                                          |
| 146. The pulse duration cannot be changed under any circumstances or by any action of the sonographer.                                                                                                                                              | <b>False.</b> A sonographer can alter the pulse duration by using a different imaging transducer or ultrasound system.                                                                                                                                                                                                                                                                     |
| 147. What is the pulse duration equal to?<br>A. frequency multiplied by period<br>B. period multiplied by wavelength<br>C. the number of cycles in the pulse divided by the wavelength<br>D. period multiplied by the number of cycles in the pulse | <b>D.</b> The pulse duration is the total time that the transducer is producing a pulse. The pulse duration is equal to the time to make a single cycle (the period) multiplied by the number of cycles that make up the pulse. For example, if there are 6 cycles in a pulse, each with a period of 0.2 $\mu\text{sec}$ , then the pulse duration is $6 \times 0.2 = 1.2 \mu\text{sec}$ . |
| 148. What happens to the pulse duration when a sonographer decreases the maximum imaging depth in an ultrasound scan?<br>A. increases<br>B. decreases<br>C. remains the same<br>D. cannot be determined                                             | <b>C.</b> The time that a transducer is "pulsing" does not change with alterations in depth of view.                                                                                                                                                                                                                                                                                       |



| Questions                                                                                                                                                                                                                                                                                                                                                | Answers                                                                                                                                                                                                                                                                                                                                                                          |
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| <p>149. The spatial pulse length describes certain characteristics of an ultrasound pulse. What are its units?</p> <p>A. time<br/>B. hertz<br/>C. meters<br/>D. none; it is unitless</p>                                                                                                                                                                 | <p>C. Spatial pulse length is the distance that a pulse occupies in space. Its length is measured from the beginning to the end of the pulse. It can be reported in any unit of distance.</p>                                                                                                                                                                                    |
| <p>150. In diagnostic imaging, what determines the spatial pulse length?</p> <p>A. the ultrasound system<br/>B. the medium through which the pulse travels<br/>C. both A and B<br/>D. neither A nor B</p>                                                                                                                                                | <p>C. The spatial pulse length is the distance, or length, of a pulse. It depends, in part, upon the wavelength of each cycle in the pulse. Wavelength depends upon both the source of the sound and the medium through which the sound travels. The length of the entire pulse also depends upon both the source and the medium.</p>                                            |
| <p>151. Which of the following best describes the spatial pulse length?</p> <p>A. frequency multiplied by wavelength<br/>B. PRF multiplied by wavelength<br/>C. wavelength multiplied by the number of cycles in the pulse<br/>D. duty factor multiplied by the wavelength</p>                                                                           | <p>C. The total length of a pulse equals the length of each cycle in the pulse multiplied by the number of cycles in the pulse. Imagine the pulse as a train made up of a number of boxcars. The train's length (the spatial pulse length) equals the length of each car (the wavelength) multiplied by the number of cars in the train (the number of cycles in the pulse).</p> |
| <p>152. Two transducers send ultrasound pulses into soft tissue. One transducer emits sound with a 4 MHz frequency, and the other produces sound at a 6 MHz frequency. Each pulse contains 4 cycles. Which has a greater spatial pulse length?</p> <p>A. the 6 MHz pulse<br/>B. the 4 MHz pulse<br/>C. they are the same<br/>D. cannot be determined</p> | <p>B. Since both pulses have the same number of cycles, the pulse whose individual cycles have a longer wavelength will have the greater overall length. In a given medium, waves with lower frequencies have longer wavelengths. The 4 MHz wave has a longer wavelength than the 6 MHz wave and therefore will have a longer spatial pulse length.</p>                          |

| Questions                                                                                                                                                                                                                                                               | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
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| <p>153. Using a specific transducer, what happens to the spatial pulse length as the sonographer increases the maximum imaging depth?</p> <p>A. increases<br/>B. decreases<br/>C. remains the same<br/>D. cannot be determined</p>                                      | <p><b>C.</b> The spatial pulse length is determined by the number of cycles in the pulse and the wavelength of each cycle. With the same system, these factors are unchanged, and the spatial pulse length remains the same.</p>                                                                                                                                                                                                                                        |
| <p>154. True or False? While imaging soft tissue, the spatial pulse length does not change as long as the components of the ultrasound system are the same.</p>                                                                                                         | <p><b>True.</b> The overall length of a pulse is equal to the wavelength multiplied by the number of cycles in the pulse. Using a particular ultrasound system and transducer, the pulse length cannot change.</p>                                                                                                                                                                                                                                                      |
| <p>155. On what does the pulse repetition period depend?</p> <p>A. the source of the sound wave<br/>B. the medium through which the pulse travels<br/>C. both A and B<br/>D. neither A nor B</p>                                                                        | <p><b>A.</b> Similar to the PRF, the pulse repetition period depends only on the ultrasound system. The pulse repetition period is the time from the start of one pulse to the start of the next pulse and includes the pulse duration and the receiving time. When the sonographer adjusts the depth of view, the pulse repetition period is altered. To be more exact, the listening time is lengthened with deeper imaging and shortened with shallower imaging.</p> |
| <p>156. A sonographer adjusts the maximum imaging depth of an ultrasound system. Which of the following also changes? (More than one answer may be correct.)</p> <p>A. pulse repetition period<br/>B. wavelength<br/>C. pulse repetition frequency<br/>D. frequency</p> | <p><b>A and C.</b></p> <p>As imaging depth is altered, the PRF and pulse repetition period change.</p> <p>The wavelength and frequency remain constant, as these terms describe the attributes of a single cycle within the pulse, and are not affected by alterations in imaging depth.</p>                                                                                                                                                                            |

| Questions                                                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                                  |
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| <p>157. Which of the following correctly describes pulse repetition period?</p> <ul style="list-style-type: none"> <li>A. the product of wavelength and propagation speed</li> <li>B. the reciprocal of the frequency</li> <li>C. the sum of the pulse's "on" time and the listening "off" time</li> <li>D. the time that the transducer is pulsing</li> </ul> | <p><b>C.</b> The pulse repetition period is the actual time from the start of one pulse to the start of the next pulse. It is equal to the time that the transducer is pulsing (the pulse duration) plus the time that the ultrasound system is listening for reflected echoes.</p>                                                                      |
| <p>158. What happens to the pulse repetition period if the sonographer decreases the maximum imaging depth achieved in an ultrasound scan?</p> <ul style="list-style-type: none"> <li>A. increases</li> <li>B. decreases</li> <li>C. remains the same</li> <li>D. cannot be determined</li> </ul>                                                              | <p><b>B.</b> As the maximum imaging depth, or depth of view, is decreased, the interval of time during which the ultrasound machine listens for returning echoes is diminished. As a result of this shorter listening time, the pulse repetition period is shortened. Simply stated, pulse repetition period and depth of view are directly related.</p> |
| <p>Two ultrasound systems, one producing sound with a frequency of 3 MHz and the other at 6 MHz, are used to image a patient. The maximum imaging depth of both exams is 8 cm. Are the following 4 statements true or false?</p>                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                          |
| <p>159. The period of the 3 MHz sound is greater than the period of the 6 MHz sound.</p>                                                                                                                                                                                                                                                                       | <p><b>True.</b> The period of a wave is the time that is required to complete one single cycle. A sound signal's period and frequency are reciprocals; therefore, the lower the frequency, the higher the period. In this case, the 3 MHz wave has a period twice as long as the 6 MHz wave.</p>                                                         |
| <p>160. The wavelength of the 3 MHz ultrasound is greater than the 6 MHz sound.</p>                                                                                                                                                                                                                                                                            | <p><b>True.</b> Wavelength is the distance that a single cycle of a pulse occupies in space. When traveling through a particular medium, cycles from waves with lower frequencies have longer wavelengths. Thus, cycles from a 3 MHz wave have longer wavelengths than those from a 6 MHz wave.</p>                                                      |



| Questions                                                                                                                                              | Answers                                                                                                                                                                                                                                                             |
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| 161. The pulses produced by both systems travel at the same speed in the patient.                                                                      | <b>True.</b> All sound waves travel in the same medium at identical speeds. Frequency and speed are unrelated.                                                                                                                                                      |
| 162. The PRF of the 6 MHz transducer is greater than the PRF of the 3 MHz transducer.                                                                  | <b>False.</b> The PRF is derived from the maximum imaging depth as established by the sonographer. The PRF changes only when the imaging depth changes. Since the depth of view for both systems is the same, the PRFs are also the same.                           |
| The maximum imaging depth during an exam is unchanged. A new transducer with a longer pulse duration is used. Are the next 4 statements true or false? |                                                                                                                                                                                                                                                                     |
| 163. The pulse repetition period is increased.                                                                                                         | <b>False.</b> Pulse repetition period is determined by the depth of view. In this case, the maximum depth is unchanged, so the pulse repetition period is also unchanged.                                                                                           |
| 164. The pulse repetition frequency is increased.                                                                                                      | <b>False.</b> Pulse repetition frequency and pulse repetition period are reciprocals. If the pulse repetition period is unchanged, then the PRF must also remain unchanged.                                                                                         |
| 165. The duty factor is increased.                                                                                                                     | <b>True.</b> Duty cycle is calculated by dividing the pulse duration by the pulse repetition period (PRP). In this example, the PRP is unchanged. By changing to a transducer with a longer pulse duration while the PRP stays constant, the duty factor increases. |
| 166. The frequency is increased.                                                                                                                       | <b>False.</b> After reading the information in the question, you will note that nothing is stated regarding the frequency of sound emitted by the transducer. Therefore, nothing can be concluded regarding frequency.                                              |
| 167. What are the units of pulse repetition frequency (PRF)?<br>A. seconds<br>B. 1/seconds<br>C. mm/ $\mu$ s<br>D. seconds <sup>-2</sup>               | <b>B.</b> Pulse repetition frequency is the number of pulses that are produced by the ultrasound system in one second. PRF has the same units as frequency, and these units are hertz, Hz, or per second.                                                           |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                                                                               |
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| <p>168. The pulse repetition frequency of ultrasound produced by a transducer typical of diagnostic imaging systems ____.</p> <ul style="list-style-type: none"> <li>A. can be changed by the sonographer</li> <li>B. depends on the medium through which the sound travels</li> <li>C. is unchanged as long as the same ultrasound system is used</li> <li>D. has nothing to do with clinical imaging</li> </ul> | <p><b>A.</b> The pulse repetition frequency (PRF) is inversely related to the maximum imaging depth that is achieved during an exam. As the sonographer increases the maximum imaging depth, the PRF must decrease.</p> <p>This occurs because the transducer must wait a longer time for echoes to return from deeper depths. Sonographers, therefore, alter the PRF when they adjust the maximum imaging depth.</p> |
| <p>169. In diagnostic imaging, what establishes the pulse repetition frequency?</p> <ul style="list-style-type: none"> <li>A. the source of the sound</li> <li>B. the medium through which the sound travels</li> <li>C. both A and B</li> <li>D. neither A nor B</li> </ul>                                                                                                                                      | <p><b>A.</b> The sole determinant of the pulse repetition frequency is the source of the acoustic wave, the ultrasound system. The medium through which the sound travels does not directly affect the pulse repetition frequency.</p>                                                                                                                                                                                |
| <p>170. When a sonographer increases the maximum imaging depth during an exam, what happens to the PRF?</p> <ul style="list-style-type: none"> <li>A. PRF increases</li> <li>B. PRF decreases</li> <li>C. remains unchanged</li> </ul>                                                                                                                                                                            | <p><b>B.</b> When the depth of view is increased, the system waits and listens a longer time for reflections. This reduces the system's ability to send out as many pulses per second. Hence, as imaging depth increases, the pulse repetition frequency decreases. Imaging depth and PRF are inversely related.</p>                                                                                                  |
| <p>171. True or False? The pulse repetition frequency and the frequency are unrelated.</p>                                                                                                                                                                                                                                                                                                                        | <p><b>True.</b> PRF and frequency are unrelated. The PRF is determined only by the depth of view. The frequency is determined by the characteristics of the transducer.</p>                                                                                                                                                                                                                                           |
| <p>172. The pulse repetition frequency is the ____.</p> <ul style="list-style-type: none"> <li>A. product of the wavelength and propagation speed</li> <li>B. reciprocal of the period</li> <li>C. sum of pulse duration and listening time</li> <li>D. reciprocal of pulse repetition period</li> </ul>                                                                                                          | <p><b>D.</b> The PRF and the pulse repetition period are reciprocals. For example, if the PRF is 100 per second, then the pulse repetition period is one-hundredth of a second. If the system creates five hundred pulses per second, then the pulse repetition period is 1/500 of a second.</p>                                                                                                                      |



| Questions                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
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| <p>173. What is a typical value for the duty factor (also called the duty cycle) of pulsed sound waves used in diagnostic imaging?</p> <p>A. 0.001 msec<br/>B. 0.001 kg/cm<sup>3</sup><br/>C. 0.75<br/>D. 0.001</p> | <p>D. Duty factor, or duty cycle, is the percentage or fraction of time that an ultrasound system produces an acoustic signal, or is transmitting. Typically, ultrasound transducers spend the vast majority of time receiving, and only a small fraction of time transmitting an acoustic signal.</p>                                                                                                                                                                                                             |
| <p>174. What is the value of the duty cycle for continuous wave ultrasound?</p> <p>A. 100<br/>B. 1%<br/>C. 1000%<br/>D. none of the above</p>                                                                       | <p>D. The duty factor for continuous wave ultrasound is 1.0 or 100%. This means that the transducer is producing an acoustic signal at all times. None of the answers indicate this: 100 is not 100%, 1% means one-hundredth and is incorrect, and 1000% means 10 times and is also false.</p>                                                                                                                                                                                                                     |
| <p>175. In the case of pulsed ultrasound, what is the maximum value of the duty factor?</p> <p>A. 100%<br/>B. 1<br/>C. less than 100%<br/>D. none of the above</p>                                                  | <p>C. This question is a bit tricky. When dealing with a pulsed ultrasound system, at least a tiny bit of time must be spent listening rather than transmitting. Therefore, the percentage of time transmitting must be less than 1 or 100%. If the percentage equals 100%, the system is continuous wave. The correct choice, C, distinguishes between pulsed and continuous wave by stating that the maximum value of the duty cycle must be <i>less than</i> 100% for a pulsed system.</p>                      |
| <p>176. While using a particular imaging system, what happens to the duty factor when the depth of view increases?</p> <p>A. increases<br/>B. decreases<br/>C. unchanged</p>                                        | <p>B. Duty factor is inversely related to depth of view. As the system images to a greater depth, the system requires more time to listen for reflections, and the duty factor decreases.</p> <p>The duty factor is the fraction or percentage of time that an imaging system is transmitting. It is equal to the pulse duration divided by the pulse repetition period. Under normal operation, the pulse duration never changes. However, as depth of view increases, the pulse repetition period increases.</p> |



| Questions                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                      |
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| 177. True or False? The sonographer alters the duty cycle when adjusting the maximum imaging depth of a scan.                                                                                                                                     | <b>True.</b> The duty cycle is the percentage of time that an ultrasound system is creating an acoustic wave. Duty factor is inversely related to depth of view. Duty factor decreases when depth of view increases.                                                                                                                                         |
| 178. True or False? The duty factor is a characteristic of an ultrasound and transducer system and does not change as long as the system components remain unchanged.                                                                             | <b>False.</b> The duty cycle changes when the sonographer adjusts the maximum imaging depth during an exam.                                                                                                                                                                                                                                                  |
| 179. While using the same ultrasound machine and transducer, which of the following can a sonographer alter? (More than one answer may be correct.)<br>A. pulse repetition period<br>B. PRF<br>C. frequency<br>D. duty cycle<br>E. pulse duration | <b>A, B, and D.</b><br>While adjusting the desired maximum imaging depth in an exam, the sonographer adjusts the pulse repetition period and the PRF. The duty factor is also altered.<br><br>Unlike choices A, B and D, the frequency of the ultrasound and the pulse duration are fixed once a transducer is selected. These parameters cannot be altered. |
| 180. Which of the following terms does not belong with the others?<br>A. increased depth of view<br>B. increased duty factor<br>C. increased pulse repetition period<br>D. decreased pulse repetition frequency                                   | <b>B.</b> Increased duty factors are related to shallower imaging. The other three selections are consistent with deeper imaging.                                                                                                                                                                                                                            |
| 181. Which of the following terms does not belong with the others?<br>A. increased depth of view<br>B. decreased duty factor<br>C. increased pulse repetition period<br>D. decreased spatial pulse length                                         | <b>D.</b> Spatial pulse length is unrelated to alterations in depth of view. The other three selections are all related to deeper imaging.                                                                                                                                                                                                                   |

| Questions                                                                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                                                                                                     |
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| <p>182. What is the importance of describing sound beam intensities in a variety of ways with regard to space and time?</p> <ul style="list-style-type: none"> <li>A. it allows better transducer design</li> <li>B. it's important when studying bioeffects</li> <li>C. it optimizes image quality</li> <li>D. harmonics can be measured</li> </ul> | <p>B. Describing the intensity of sound beams as they vary in time and in space is important in the study of bioeffects.</p>                                                                                                                                                                                                                                                |
| <p>183. Which intensity is most closely correlated to tissue heating?</p> <ul style="list-style-type: none"> <li>A. SPTP</li> <li>B. SATP</li> <li>C. SPTA</li> <li>D. SATA</li> </ul>                                                                                                                                                               | <p>C. The SPTA intensity relates most closely to tissue temperature elevation.</p>                                                                                                                                                                                                                                                                                          |
| LOGARITHMS and DECIBELS                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                             |
| <p>184. The logarithm of a numeral is defined as how many times ____ must be multiplied together to get that numeral.</p> <ul style="list-style-type: none"> <li>A. 1</li> <li>B. 2</li> <li>C. 5</li> <li>D. 10</li> </ul>                                                                                                                          | <p>D. The logarithm of a numeral is equal to the number of <b>tens</b> that are multiplied together to result in that number.</p>                                                                                                                                                                                                                                           |
| <p>185. What is a decibel?</p> <ul style="list-style-type: none"> <li>A. the absolute value of a number</li> <li>B. a range of values</li> <li>C. a relationship between two numbers</li> <li>D. none of the above</li> </ul>                                                                                                                        | <p>C. A decibel represents a relationship between two numbers. A decibel is a <i>relative measure</i> of intensity or power. The term "relative" indicates that we are not dealing with an absolute power (such as 600 watts), but rather with how the power is related to a reference level (for example, the current signal is 50% as strong as the reference level).</p> |
| <p>186. Decibel notation is a ____ between two numbers.</p> <ul style="list-style-type: none"> <li>A. difference</li> <li>B. sum</li> <li>C. product</li> <li>D. ratio</li> </ul>                                                                                                                                                                    | <p>D. Decibels are calculated by dividing the final strength of a signal by the starting strength. Thus, decibel notation is a ratio between two numbers.</p>                                                                                                                                                                                                               |

| Questions                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                      |
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| <p>187. Which of the following reports the relative strength of an ultrasound wave?</p> <p>A. decibels<br/>B. watts<br/>C. <math>\text{W}/\text{cm}^2</math><br/>D. pascals</p>                                                                    | <p><b>A.</b> The <i>relative</i> strength of a sound beam may be reported in decibels. The term "relative" indicates a comparison between two values, such as a beam has decreased in strength by 50%.</p> <p>Choices B, C, and D are not comparisons, but absolute measurements.</p>        |
| <p>188. The scale associated with decibel notation is ____.</p> <p>A. linear<br/>B. discrete<br/>C. logarithmic<br/>D. additive</p>                                                                                                                | <p><b>C.</b> Decibel notation is based on the mathematical relationship of logarithms.</p>                                                                                                                                                                                                   |
| <p>189. What is the decibel representation when an acoustic signal is amplified?</p> <p>A. positive<br/>B. negative<br/>C. equal to zero</p>                                                                                                       | <p><b>A.</b> When a signal is amplified, its magnitude increases and it becomes stronger. In decibel notation, an increase in signal strength is described with positive decibels. Positive dB means "getting bigger."</p>                                                                   |
| <p>190. What is the decibel notation for an acoustic signal that is attenuated?</p> <p>A. positive<br/>B. negative<br/>C. equal to zero</p>                                                                                                        | <p><b>B.</b> When a signal is attenuated, its magnitude decreases and it becomes weaker. In decibel notation, a decrease in signal strength is described with negative decibels.</p> <p>Negative dB means "getting smaller."</p>                                                             |
| <p>191. The intensity of a signal declines from <math>1.5 \text{ mW}/\text{cm}^2</math> to <math>0.75 \text{ mW}/\text{cm}^2</math>. How many decibels is this change in intensity?</p> <p>A. 3 dB<br/>B. 0.75 dB<br/>C. -0.75 dB<br/>D. -3 dB</p> | <p><b>D.</b> A decline in intensity to one-half of the original level is a change of -3 dB. When the new level is less than the reference level, the reported decibels must be negative. When the new intensity is greater than the reference level, the change in decibels is positive.</p> |



| Questions                                                                                                                                                                                                                  | Answers                                                                                                                                                                                                                                                                                                                                                           |
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| <p>192. The power in a wave is increased to ten times its original value. How many decibels describe this change?</p> <p>A. 3<br/>B. 6<br/>C. 10<br/>D. 20</p>                                                             | <p>C. An increase of ten times the original power of a wave is reported as +10 dB.</p>                                                                                                                                                                                                                                                                            |
| <p>193. How many decibels represent a 100-fold increase in the intensity of an acoustic pulse?</p> <p>A. 10<br/>B. 20<br/>C. 100<br/>D. 6</p>                                                                              | <p>B. An increase of 100 times the intensity of a wave is equal to 20 dB. Each 10 dB indicates a tenfold increase. Therefore, 20 dB (two 10 dB increases) means a pair of tenfold increases, <math>10 \times 10 = 100</math>.</p>                                                                                                                                 |
| <p>194. The intensity of an ultrasound wave is changed by -6 dB. This means that the current intensity is ____ as much as its original level.</p> <p>A. one-tenth<br/>B. four times<br/>C. one-fourth<br/>D. one-sixth</p> | <p>C. A change in intensity of -6 dB indicates that only one-fourth of the initial intensity remains. The minus sign indicates a decrease in signal magnitude. Each -3 dB change means that one-half of the original intensity remains. Since there are two sets of -3 dB, one-half multiplied by one-half indicates that there is only one-fourth remaining.</p> |
| <p>195. What units are used to describe attenuation?</p> <p>A. watts<br/>B. watts/cm<sup>2</sup><br/>C. macro<br/>D. decibels</p>                                                                                          | <p>D. Attenuation is measured in decibels. Attenuation is reported as a relative change in strength, not an absolute change.</p>                                                                                                                                                                                                                                  |
| <p>196. What does a 3 dB change in a value intensity mean?</p> <p>A. the value has doubled<br/>B. the value has tripled<br/>C. the value has increased 30%<br/>D. the value has increased ten times</p>                    | <p>A. A 3 decibel change in the intensity indicates that the value has doubled.</p>                                                                                                                                                                                                                                                                               |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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| <b>ATTENUATION, REFLECTION, and SCATTERING</b>                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <p>197. As sound propagates through a medium, the total power in the wave decreases. What is this entire process called?</p> <ul style="list-style-type: none"> <li>A. absorption</li> <li>B. scattering</li> <li>C. attenuation</li> <li>D. reflection</li> </ul>                                                                                                                                                                       | <p>C. As a wave propagates through a medium, its power diminishes. This is attenuation. Choices A, B, and D are all components of or contributors to attenuation.</p>                                                                                                                                                                                                                                                                                               |
| <p>198. Attenuation is determined by which of the following factors?</p> <ul style="list-style-type: none"> <li>A. density and stiffness of the medium</li> <li>B. frequency of sound and propagation speed</li> <li>C. PRF of sound and path length</li> <li>D. path length and frequency of sound</li> </ul>                                                                                                                           | <p>D. The factors that determine the degree to which a sound beam weakens are:</p> <ol style="list-style-type: none"> <li>1. the distance that the sound travels, and</li> <li>2. the frequency of the sound.</li> </ol>                                                                                                                                                                                                                                            |
| <p>199. An acoustic wave is traveling through soft tissue. Its intensity undergoes six decibels of attenuation. How does the final intensity of the wave relate to the intensity of the wave when it started its journey?</p> <ul style="list-style-type: none"> <li>A. it is now four times larger</li> <li>B. it is now six times larger</li> <li>C. it is now one-fourth as large</li> <li>D. it is now one-tenth as large</li> </ul> | <p>C. When a wave undergoes 6 dB of attenuation, the intensity of the wave is decreased to one-fourth of its initial value. The term attenuation means "to weaken, or reduce." Attenuation always describes a reduction in the intensity of the wave. Six decibels of attenuation is made up of two groups of -3 dB. Each -3 dB indicates a halving of intensity. One-half multiplied by one-half means that only one-fourth of the original intensity remains.</p> |
| <p>200. Which of the following is <i>not</i> one of the physical processes that contributes to attenuation of ultrasound waves passing through soft tissue?</p> <ul style="list-style-type: none"> <li>A. reflection</li> <li>B. redirection of sound in many directions</li> <li>C. focusing</li> <li>D. conversion of acoustic energy to heat</li> </ul>                                                                               | <p>C. Focusing does not contribute to the attenuation process.</p> <p>In contrast, choices A, B, and D reduce the intensity of a wave as it propagates.</p>                                                                                                                                                                                                                                                                                                         |

| Questions                                                                                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                                                                              |
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| <p>201. An acoustic pulse reflects from a very smooth boundary where the irregularities on the surface of the boundary are much smaller than the pulse's wavelength. What type of reflection is most likely to occur under these circumstances?</p> <p>A. partial<br/>B. Rayleigh<br/>C. specular<br/>D. total</p> | <p>C. Reflections from a smooth boundary are specular. A mirror is a specular reflector. The waves strike this smooth boundary and reflect in an organized, systematic manner.</p> <p>A boundary is considered smooth when irregularities in its surface are smaller than the wavelength of the incident ultrasonic beam.</p>                                        |
| <p>202. A sound wave reaches a rough or irregular border between two media. Under these explicit circumstances, which process is most likely to occur?</p> <p>A. backscatter reflection<br/>B. specular reflection<br/>C. Rayleigh scattering<br/>D. refraction</p>                                                | <p>A. The smoothness or roughness of a boundary will help to determine what form of reflection takes place. Backscatter is likely to occur when the boundary has irregularities that are larger than the wavelength of the incident acoustic pulse. Diffuse reflection is another name for backscatter.</p>                                                          |
| <p>203. Which of the following is true of diffuse reflections?</p> <p>A. they're created by smooth boundaries<br/>B. they're created by large reflectors<br/>C. sound reflects in many directions<br/>D. they do not appear in soft tissue</p>                                                                     | <p>C. Diffuse reflections, also called backscatter, are dispersed in multiple directions.</p>                                                                                                                                                                                                                                                                        |
| <p>204. What is the uniform dispersion of a sound wave in many different directions after striking a very small particle?</p> <p>A. microscattering<br/>B. backscattering<br/>C. Rayleigh scattering<br/>D. total absorption</p>                                                                                   | <p>C. Rayleigh scattering is the redirection of an acoustic wave in many different directions as a result of striking a small particle. When Rayleigh scattering occurs, the dimension of the reflecting particle is usually less than the wavelength of the ultrasound wave. The amount of Rayleigh scattering also depends on the frequency of the ultrasound.</p> |



| Questions                                                                                                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                                                                                  |
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| <p>205. Which of the following is considered a Rayleigh scatterer?</p> <ul style="list-style-type: none"> <li>A. bone</li> <li>B. liver</li> <li>C. muscle</li> <li>D. blood cell</li> </ul>                                                                                                                | <p><b>D.</b> A blood cell is a Rayleigh scatterer. A red blood cell is smaller than the wavelength of the typical acoustic wave used in diagnostic imaging. When an acoustic wave strikes a blood cell, the energy within the pulse is scattered in many directions.</p> |
| <p>206. To which of the following is Rayleigh scattering related?</p> <ul style="list-style-type: none"> <li>A. half of the wavelength</li> <li>B. square root of propagation speed</li> <li>C. frequency<sup>4</sup></li> <li>D. PRF<sup>2</sup></li> </ul>                                                | <p><b>C.</b> The degree to which a wave exhibits Rayleigh scattering is related to frequency raised to the fourth power.</p> <p>That is, if the frequency is twice as high, Rayleigh scattering is increased 16-fold:</p> $2^4 = 2 \times 2 \times 2 \times 2 = 16$      |
| <p>207. As a pulse passes through soft tissue, a certain amount of acoustic energy remains in the tissue as heat. What is this constituent of attenuation called?</p> <ul style="list-style-type: none"> <li>A. scattering</li> <li>B. absorption</li> <li>C. refraction</li> <li>D. rarefaction</li> </ul> | <p><b>B.</b> The conversion of acoustic energy into heat is called absorption. This process deposits a portion of the energy from the beam into the soft tissues.</p>                                                                                                    |
| <p>208. What is the amount of attenuation per centimeter that a sound wave undergoes called?</p> <ul style="list-style-type: none"> <li>A. beam uniformity coefficient</li> <li>B. attenuation coefficient</li> <li>C. attenuation</li> <li>D. duty factor</li> </ul>                                       | <p><b>B.</b> The attenuation coefficient reports a sound beam's decibels of attenuation per centimeter. This is a useful tool as its value remains constant, regardless of the actual path length.</p>                                                                   |
| <p>209. A sound beam travels 9 cm in soft tissue. The attenuation coefficient is 3 dB/cm. What is the total attenuation that the sound beam experienced?</p> <ul style="list-style-type: none"> <li>A. 9 dB</li> <li>B. 3 dB</li> <li>C. 27 dB</li> <li>D. 18 dB</li> </ul>                                 | <p><b>C.</b> To calculate total attenuation, multiply path length by attenuation coefficient.</p> <p>In this example, the overall attenuation is</p> $3 \times 9 = 27 \text{ dB.}$                                                                                       |

| Questions                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                        |
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| <p>210. The attenuation of an acoustic wave traveling through bone is ____ its attenuation through soft tissue.</p> <p>A. greater than<br/>B. less than<br/>C. equal to</p>                                                                        | <p>A. The attenuation of ultrasound in bone is greater than its attenuation in soft tissue.</p>                                                                                                                |
| <p>211. Ultrasound waves traveling through lung tissue attenuate to a ____ extent than when traveling through soft tissue.</p> <p>A. greater<br/>B. lesser<br/>C. nearly equal</p>                                                                 | <p>A. Ultrasound attenuates more when traveling through lung tissue than when traveling through soft tissue.</p>                                                                                               |
| <p>212. Sound traveling through blood attenuates to a ____ extent than when traveling through soft tissue.</p> <p>A. greater<br/>B. lesser<br/>C. relatively equal</p>                                                                             | <p>B. Ultrasound waves attenuate less when traveling through blood than when traveling through soft tissue.</p>                                                                                                |
| <p>213. Which of these lists indicates media with increasing attenuation of ultrasound?</p> <p>A. water, lung, soft tissue, bone, air<br/>B. lung, air, soft tissue, bone<br/>C. lung, fat, muscle<br/>D. water, blood, fat, muscle, bone, air</p> | <p>D. This list orders tissues with increasing attenuation rates of ultrasound.</p>                                                                                                                            |
| <p>214. True or False? Attenuation and propagation speed are unrelated.</p>                                                                                                                                                                        | <p><b>True.</b> Attenuation and propagation speed are entirely unrelated. Attenuation is the weakening of a beam as it travels and has nothing to do with how fast it travels.</p>                             |
| <b>IMPEDANCE</b>                                                                                                                                                                                                                                   |                                                                                                                                                                                                                |
| <p>215. Acoustic impedance is a property of the ____ and has units of ____.</p> <p>A. source and medium, Imps<br/>B. medium, dB<br/>C. medium, Rayls<br/>D. medium, Ohms</p>                                                                       | <p>C. Acoustic impedance is a property of the medium through which sound travels. It is unaffected by the sound source or the characteristics of the wave itself.</p> <p>The units of impedance are Rayls.</p> |

| Questions                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                                |
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| <p>216. To calculate the acoustic impedance of a medium, one should ____ the ____ by the ____.</p> <p>A. divide, propagation speed, density<br/>         B. multiply, density, propagation speed<br/>         C. divide, density, propagation speed<br/>         D. multiply, stiffness, density</p> | <p><b>B.</b> To obtain the value of acoustic impedance, multiply the density of a medium by its propagation speed.</p>                                                                                                                                                                                 |
| <p>217. Which two attributes help establish the acoustic impedance of a medium?</p> <p>A. density and temperature<br/>         B. density and stiffness<br/>         C. stiffness and elastance<br/>         D. elasticity and compressibility</p>                                                   | <p><b>B.</b> To calculate the acoustic impedance, multiply the propagation speed of the medium by the density of the medium. A medium's propagation speed is determined by the density and the stiffness of the medium. Therefore, acoustic impedance is a property of both density and stiffness.</p> |
| <p>218. Which value is closest to the impedance of soft tissue?</p> <p>A. 1.5 kiloRayls<br/>         B. 2.5 deciRayls<br/>         C. 19 megaRayls<br/>         D. 2,000,000 Rayls</p>                                                                                                               | <p><b>D.</b> The impedance of soft tissue is in the range of 1.5 to 2.5 million Rayls.<br/>         Choices A and B are far too low, and choice C is too high.</p>                                                                                                                                     |

## INCIDENCE

|                                                                                                                                                                                          |                                                                                                 |
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| <p>219. Which of the following describes an angle with a measure of <math>45^\circ</math>?</p> <p>A. orthogonal<br/>         B. acute<br/>         C. obtuse<br/>         D. normal</p>  | <p><b>B.</b> Any angle that measures less than <math>90^\circ</math> is an acute angle.</p>     |
| <p>220. Which of the following describes an angle with a measure of <math>123^\circ</math>?</p> <p>A. orthogonal<br/>         B. acute<br/>         C. obtuse<br/>         D. normal</p> | <p><b>C.</b> Any angle that measures greater than <math>90^\circ</math> is an obtuse angle.</p> |



| Questions                                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                      |
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| <p>221. The angle between the direction of propagation and the boundary between two media is <math>90^\circ</math>. What term describes the form of incidence of the wave?</p> <p>A. not normal<br/>B. direct<br/>C. oblique<br/>D. orthogonal</p> | <p>D. Orthogonal incidence is attained when a sound wave strikes a boundary between media at exactly <math>90^\circ</math>.</p>                                                                                                                                                                              |
| <p>222. Which term does not belong in the group below?</p> <p>A. orthogonal<br/>B. at right angles<br/>C. oblique<br/>D. <math>90^\circ</math><br/>E. normal<br/>F. perpendicular</p>                                                              | <p>C. The five terms: orthogonal, at right angles, <math>90^\circ</math>, normal, and perpendicular are synonymous. Their meanings are identical.</p>                                                                                                                                                        |
| <p>223. A sound wave strikes a boundary between two media at a <math>60^\circ</math> angle. This is called ____ incidence.</p> <p>A. orthogonal<br/>B. angular<br/>C. obtuse<br/>D. oblique</p>                                                    | <p>D. Oblique incidence is always present when the angle between the direction of a wave's propagation and the boundary between two media is different than <math>90^\circ</math>.</p> <p>Oblique incidence is a definition of exclusion. That is, if the incidence is not perpendicular, it is oblique.</p> |
| <p>224. Which term has a meaning other than normal incidence?</p> <p>A. orthogonal incidence<br/>B. perpendicular incidence<br/>C. oblique incidence</p>                                                                                           | <p>C. Oblique incidence has a meaning that is different from normal incidence. Oblique incidence occurs when a wave strikes a boundary at any angle other than <math>90^\circ</math>, while normal incidence occurs when the wave strikes a boundary at exactly <math>90^\circ</math>.</p>                   |
| <p>225. What are the units of the intensity transmission coefficient?</p> <p>A. watts/square cm<br/>B. watts<br/>C. dB<br/>D. none of the above</p>                                                                                                | <p>D. The intensity transmission coefficient is defined as the <i>percentage</i> of an ultrasound beam's intensity that is transmitted as the sound wave passes through a boundary between two media. The intensity transmission coefficient is a percentage, and is reported without units.</p>             |

| Questions                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                              |
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| <p>226. What are the units of the intensity reflection coefficient?</p> <p>A. none<br/>B. <math>\text{W/cm}^2</math><br/>C. watts<br/>D. dB</p>                                                                                                                                                                                                                   | <p>A. The intensity reflection coefficient is defined as the percentage or proportion of an ultrasound beam's intensity that is reflected as the sound wave strikes a boundary between two media. The intensity reflection coefficient is reported as a percentage and therefore is unitless.</p>                                                                    |
| <p>227. A wave strikes an interface between two media and intensities are measured at the interface. What results when the reflected intensity is divided by the incident intensity?</p> <p>A. intensity reflection coefficient<br/>B. intensity transmission coefficient<br/>C. beam uniformity coefficient<br/>D. none of the above</p>                         | <p>A. Under these circumstances, when we divide the reflected intensity by the incident intensity, the result is the intensity reflection coefficient.</p> <p>The intensity reflection coefficient is the percentage of the incident intensity that is reflected as a wave strikes a boundary between two media.</p>                                                 |
| <p>228. An ultrasound wave strikes a boundary between two media. All intensities are measured directly at the boundary. What results when the transmitted intensity is divided by the reflected intensity?</p> <p>A. intensity reflection coefficient<br/>B. intensity transmission coefficient<br/>C. beam uniformity coefficient<br/>D. none of the above</p>   | <p>D. The choices of A, B, and C are all incorrect. When the transmitted intensity is divided by the reflected intensity, a number is obtained. This number has no special meaning in ultrasound physics, and is not identified by a special name.</p>                                                                                                               |
| <p>229. An ultrasound wave strikes an interface between two media. All intensities are measured directly at the interface. What results when the transmitted intensity is divided by the incident intensity?</p> <p>A. intensity reflection coefficient<br/>B. intensity transmission coefficient<br/>C. beam uniformity coefficient<br/>D. none of the above</p> | <p>B. Under these circumstances, when the transmitted intensity is divided by the incident intensity, the result is the intensity transmission coefficient. The intensity transmission coefficient is the percentage of the incident intensity that continues to propagate in the forward direction when the incident wave strikes a boundary between two media.</p> |

| Questions                                                                                                                                                                                                                              | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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| <p>230. What results when the intensity transmission coefficient and the intensity reflection coefficient are added together?</p> <p>A. incident intensity coefficient<br/>B. acoustic impedance<br/>C. total intensity<br/>D. 1.0</p> | <p>D. The sum of the intensity reflection coefficient (IRC) and the intensity transmission coefficient (ITC) equals one or 100%. The ITC is the percentage of a sound wave's intensity that is transmitted at a boundary. The IRC is the percentage of a wave's intensity that is reflected at a boundary. Since there is conservation of energy at the boundary, these percentages added together equal 100% (or 1.0).</p>                                                         |
| <p>231. What remains when the reflected intensity is subtracted from the incident intensity?</p> <p>A. 1.0<br/>B. incident intensity<br/>C. transmitted intensity coefficient<br/>D. transmitted intensity</p>                         | <p>D. At any point in time and space, there must be conservation of energy. In other words, all energy must be accounted for. The intensity in a wave as it reaches a border between two media is called the incident intensity. As the wave strikes the boundary, a portion of the wave's intensity is redirected toward the sound source. This is called the reflected intensity. The remainder of the energy continues to propagate and is called the transmitted intensity.</p> |
| <p>232. What is the maximum permissible value for both the intensity reflection coefficient and the intensity transmission coefficient?</p> <p>A. 100<br/>B. 1%<br/>C. 1<br/>D. infinity</p>                                           | <p>C. The maximum percentage of the incident intensity that either reflects or transmits is 1.0 or 100%. At the extremes, total reflection occurs (intensity reflection coefficient = 1.0) or complete transmission occurs (intensity transmission coefficient = 1.0). The upper limit of both of these coefficients is 1.0.</p>                                                                                                                                                    |
| <p>233. What is the minimum permissible value for both the intensity reflection coefficient and the intensity transmission coefficient?</p> <p>A. different from each other<br/>B. -1<br/>C. 100%<br/>D. 0</p>                         | <p>D. The minimum value for the intensity transmission and the intensity reflection coefficients is zero. At one extreme, it is possible to have total transmission and no reflection (intensity reflection coefficient = 0). At the other extreme, it is possible for total reflection to occur. No transmission would exist and the intensity transmission coefficient = 0.</p>                                                                                                   |



| Questions                                                                                                                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                      |
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| <p>234. A sound beam with an intensity of <math>45 \text{ W/cm}^2</math> strikes a boundary and 70% of the wave's intensity is reflected. How much is transmitted?</p> <p>A. <math>45 \text{ W/cm}^2</math><br/>         B. <math>25 \text{ W/cm}^2</math><br/>         C. 30%<br/>         D. 100%</p>                                                                                   | <p>C. 30% of the wave's intensity is reflected. The law of conservation of energy states that the sum of the percentage of transmitted sound and the reflected sound equals 100%.</p>                                                                                                                                        |
| REFLECTION and TRANSMISSION                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                              |
| <p>235. If the ____ of two media are different and sound strikes a border between the media at <math>90^\circ</math> incidence, then reflection will occur.</p> <p>A. conductances<br/>         B. densities<br/>         C. impedances<br/>         D. propagation speeds</p>                                                                                                            | <p>C. Under the conditions of orthogonal or normal incidence, reflection depends on differences in the acoustic impedances of the media on either side of the boundary. With normal incidence, as long as the impedances are dissimilar, reflection will always occur.</p>                                                   |
| <p>236. True or False? The proportion of the incident intensity that is reflected at a border between two media will increase as the impedances of the media become increasingly dissimilar.</p>                                                                                                                                                                                          | <p>True. As sound waves strike the border between two media, reflection occurs if their impedances are different. Greater differences between the two impedances create stronger reflections. If the impedances are only slightly different, then a weak reflection will be produced.</p>                                    |
| <p>237. A sound pulse strikes a boundary between two media with normal incidence. The speed of sound in the two media are very different; however, the impedances of the media are identical. What will happen?</p> <p>A. a big echo will be produced<br/>         B. a medium echo will result<br/>         C. a small echo will result<br/>         D. there will be no echo at all</p> | <p>D. When a sound wave is normally incident at a boundary, reflection will occur only when the media have dissimilar impedances. In this example, the wave is normally incident but the media have identical impedances. Under these circumstances, no reflection will occur and 100% of the sound will be transmitted.</p> |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                     | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
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| <p>238. Two acoustic waves strike a boundary between two media. The waves are traveling in a direction <math>90^\circ</math> to the boundary. Reflection of these waves depends on differences in the ____.</p> <ul style="list-style-type: none"><li>A. frequencies of the two waves</li><li>B. propagation speeds of the two media</li><li>C. amplitudes of the two waves</li><li>D. impedances of the two media</li></ul>  | <p>D. With normal incidence, reflection will occur at a boundary when the media on either side of the boundary have different acoustic impedances. Reflection is not dependent on the waves' characteristics such as amplitude and frequency. With normal impedance, only one condition must be met for reflection to take place: the impedances of the media on either side of the boundary must be different.</p>                                                                                                                                                                                                                                                                                                                                 |
| <p>239. An ultrasound wave approaches an interface between two media at a <math>90^\circ</math> angle. The propagation speeds and the densities of the two media are different. Which is correct?</p> <ul style="list-style-type: none"><li>A. reflection will definitely occur</li><li>B. reflection will definitely not occur</li><li>C. refraction may occur</li><li>D. none of the above</li></ul>                        | <p>D. The facts presented indicate that the propagation speeds and the densities of the two media are different, but this information is insufficient to determine whether reflection will take place. The important fact is whether the impedances of the media are different. If the impedances of the media are different, then reflection will occur. If the impedances are the same, then reflection will not occur.</p> <p>In this case, since we are unsure as to whether the impedances of the media are the same, we are unsure whether choices A or B are correct. Choice C is incorrect because refraction will never occur when a sound wave strikes a boundary at a <math>90^\circ</math> angle. The only appropriate answer is D.</p> |
| <p>240. An ultrasound wave strikes an interface between two media at a <math>90^\circ</math> angle. The propagation speeds of the media are identical. However, the densities of the media are different. Which is true?</p> <ul style="list-style-type: none"><li>A. reflection will definitely occur</li><li>B. reflection will definitely not occur</li><li>C. refraction may occur</li><li>D. none of the above</li></ul> | <p>A. Reflection will definitely occur. With normal incidence, reflection will occur when the impedances of the media on either side of the boundary are different from each other. In this example, the densities of the media are different while their propagation speeds are the same. Since impedance is propagation speed multiplied by density, it follows that the acoustic impedances of the media bordering the interface are indeed different. Reflection will occur.</p>                                                                                                                                                                                                                                                                |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                                                                                      |
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| <p>241. An acoustic wave is traveling from medium X to medium Z. Medium X has a propagation speed of 1,457 m/sec and an impedance of 1.44 MRayls. Medium Z's propagation speed is 1,644 m/sec and its impedance is 1.26 MRayls. The angle of incidence is <math>32^\circ</math>. What is true of the angle of reflection?</p> <p>A. it is greater than <math>32^\circ</math><br/>         B. it is equal to <math>32^\circ</math><br/>         C. it is less than <math>32^\circ</math><br/>         D. cannot be determined</p> | <p><b>B.</b> This is a tricky question. In cases of oblique incidence, <b>the angle of reflection is always equal to the angle of incidence.</b></p> <p>Simply put, if the incident angle is <math>32^\circ</math>, then the reflection angle is <math>32^\circ</math>. All information regarding the propagation speeds and acoustic impedances of media X and media Z are irrelevant in this question.</p> |
| <p>242. True or False? When reflection occurs with oblique incidence, the angle of reflection equals the angle of incidence. This is known as Snell's Law.</p>                                                                                                                                                                                                                                                                                                                                                                   | <p><b>False.</b> It is indeed true that the angle of reflection is equal to the angle of incidence when reflection occurs at an oblique incident angle. The falsehood in this statement is that this is not Snell's Law.</p>                                                                                                                                                                                 |
| SNELL'S LAW and REFRACTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p>243. What event does Snell's Law govern?</p> <p>A. transmission<br/>         B. refraction<br/>         C. impedance</p>                                                                                                                                                                                                                                                                                                                                                                                                      | <p><b>B.</b> Snell's Law defines the physics of refraction.</p>                                                                                                                                                                                                                                                                                                                                              |
| <p>244. Which of the following best describes the process described by Snell's law?</p> <p>A. reflection with normal incidence<br/>         B. reflection with oblique incidence<br/>         C. transmission with normal incidence<br/>         D. transmission with oblique incidence</p>                                                                                                                                                                                                                                      | <p><b>D.</b> Snell's Law defines the physics of refraction. Refraction describes the behavior of sound beams that transmit after striking a boundary obliquely. Refraction is "transmission with a bend."</p>                                                                                                                                                                                                |
| <p>245. True or False? Refraction occurs at the border between two media if and only if there is oblique incidence of the wave at the boundary.</p>                                                                                                                                                                                                                                                                                                                                                                              | <p><b>True.</b> Refraction cannot occur if a wave is normally incident to the boundary between two media. It can occur only if the incident wave is oblique to the boundary.</p>                                                                                                                                                                                                                             |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                                       |
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| <p>246. What conditions are necessary for refraction to occur at a boundary between two media?</p> <ol style="list-style-type: none"> <li>unequal acoustic impedances and normal incidence at the boundary</li> <li>unequal densities of the media and normal incidence at the boundary</li> <li>dissimilar propagation speeds and oblique incidence at the boundary</li> <li>different elasticities of the media and oblique incidence</li> </ol>                                                                                                                                             | <p>C. The two conditions required for refraction are:</p> <ol style="list-style-type: none"> <li>a sound wave must be obliquely incident to the border between two media, and</li> <li>the media on either side of the border must have dissimilar propagation speeds. Refraction occurs during transmission of a wave from one medium to another.</li> </ol> |
| <p>247. True or False? Refraction always occurs at the interface between two media when the propagation speeds of the media are unequal.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <p><b>False.</b> A sound wave refracts at the boundary between two media when <i>two</i> conditions are satisfied:</p> <ol style="list-style-type: none"> <li>the sound beam must be obliquely incident, and</li> <li>the propagation speeds of the two media must be different from each other.</li> </ol>                                                   |
| <p>248. An acoustic wave is traveling from medium X into medium Z. Medium X has a <u>propagation speed of 1,457 m/sec</u> and an <u>impedance of 1.44 MRayls</u>. Medium Z has a <u>propagation speed of 1,644 m/sec</u> and an <u>impedance of 1.26 MRayls</u>. The angle of incidence is <math>32^\circ</math>. What is true of the angle of the transmitted wave?</p> <ol style="list-style-type: none"> <li>it is greater than <math>32^\circ</math></li> <li>it is equal to <math>32^\circ</math></li> <li>it is less than <math>32^\circ</math></li> <li>cannot be determined</li> </ol> | <p>A. With refraction, the relationship between the angle of incidence and the angle of transmission is defined by Snell's Law. <b>When the propagation speed of the medium that the sound is entering exceeds the propagation speed of the medium that the sound is currently in, the angle of transmission is greater than the incident angle.</b></p>      |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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| <p>249. An acoustic wave in medium B is traveling toward medium A. The sound beam strikes the boundary at a <math>45^\circ</math> angle. The propagation speed is 1,547 m/sec for medium A and 1,745 m/sec for medium B. What is true of the angle of transmission?</p> <p>A. it is greater than <math>45^\circ</math><br/>         B. it is less than <math>45^\circ</math><br/>         C. it is equal to <math>45^\circ</math><br/>         D. cannot be determined</p>                                                                                                        | <p><b>B.</b> With refraction, when the medium that the sound is in has a greater propagation speed than the propagation speed of the medium that the wave is entering, the angle of transmission is less than the angle of incidence. In this case, the angle of transmission is less than <math>45^\circ</math> because the sound wave is entering a slower medium than the one through which it is currently propagating.</p>                                                                                                                                                                                                                                                                                                                              |
| <p>250. True or False? The period of a sound wave determines whether refraction will occur.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <p><b>False.</b> Refraction does not depend upon the characteristics of a wave. Refraction only depends upon the incidence of the sound beam and the speeds of the media.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <p>251. A wave of acoustic energy is leaving soft tissue and transmitting into fat with an <math>86^\circ</math> incident angle. What is true of the angle of transmission?</p> <p>A. it is equal to <math>86^\circ</math><br/>         B. it is less than <math>86^\circ</math><br/>         C. it is greater than <math>86^\circ</math><br/>         D. cannot be determined</p>                                                                                                                                                                                                | <p><b>B.</b> The angle of transmission will be less than the angle of incidence. Fat's propagation speed is less than that of soft tissue. The angle of transmission is less than the angle of incidence when a wave travels into a second medium that reduces the wave's propagation speed. In this example, the incidence is oblique, and fat has a lower speed than soft tissue.</p>                                                                                                                                                                                                                                                                                                                                                                      |
| <p>252. An acoustic wave is in medium A and traveling toward medium B. The sound beam's angle of transmission into medium B with relation to the boundary is <math>79^\circ</math>. Sound's propagation speed is 1,547 m/sec in medium A and 1,745 m/sec in medium B. If reflection and transmission both occur at the boundary, what can be said of the reflection angle?</p> <p>A. it is greater than <math>79^\circ</math><br/>         B. it is less than <math>79^\circ</math><br/>         C. it is equal to <math>79^\circ</math><br/>         D. cannot be determined</p> | <p><b>B.</b> Two steps are required to determine that the angle of reflection is less than <math>79^\circ</math>.</p> <p>1. We know that the transmission angle is <math>79^\circ</math> and that the propagation speed of medium A is less than that of medium B. From this, we can derive information about the angle of incidence. Since the speed of medium B is greater than the speed of medium A, the angle of transmission is greater than the angle of incidence. Thus, the angle of incidence must be less than <math>79^\circ</math>.</p> <p>2. The angle of reflection is equal to the angle of incidence. Since the angle of incidence is less than <math>79^\circ</math>, the angle of reflection is also less than <math>79^\circ</math>.</p> |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                                                                                                  |
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| <p>253. Sound propagates from one medium with a density of <math>1.16 \text{ kg/m}^3</math> to a second medium with a density of <math>1.02 \text{ kg/m}^3</math>. If the angle of transmission is <math>49^\circ</math>, what can be correctly stated about the angle of incidence?</p> <p>A. it is less than <math>49^\circ</math><br/>         B. it is equal to <math>49^\circ</math><br/>         C. it is greater than <math>49^\circ</math><br/>         D. it cannot be determined</p> | <p>D. No definite statement can be made about the angle of incidence. Since the propagation speeds of the media are unknown, we cannot make any conclusions about the incident angle. The density of a medium helps to determine the propagation speed, but knowledge of only the density without knowledge of a tissue's stiffness is insufficient to deduce which of the two media has a higher propagation speed.</p> |
| <b>TIME of FLIGHT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <p>254. How long does it take for sound to make a round trip to and from the skin's surface to a reflector depth of 1 cm in soft tissue?</p> <p>A. 13 <math>\mu\text{s}</math><br/>         B. 150 ms<br/>         C. 15 <math>\mu\text{s}</math><br/>         D. 2 seconds</p>                                                                                                                                                                                                                | <p>A. In soft tissue, sound can travel to and return from a depth of 1 cm (a total distance of 2 cm) in 13 microseconds (13 millionths of a second).</p>                                                                                                                                                                                                                                                                 |
| <p>255. In soft tissue, sound travels to a reflector and back to the transducer in 39 <math>\mu\text{s}</math>. How deep is the reflector?</p> <p>A. 2 cm<br/>         B. 6 cm<br/>         C. 3 cm<br/>         D. cannot be determined</p>                                                                                                                                                                                                                                                   | <p>C. For each 13 <math>\mu\text{s}</math>, sound travels a round trip depth of 1 centimeter. Thus, in 39 <math>\mu\text{s}</math>, sound travels to and returns from a depth of 3 cm.</p>                                                                                                                                                                                                                               |
| <p>256. In soft tissue, sound travels to a reflector and back to the transducer in 39 <math>\mu\text{s}</math> (39 microseconds or 39 millionths of a second). What is the total distance that the pulse traveled?</p> <p>A. 2 cm<br/>         B. 6 cm<br/>         C. 3 cm<br/>         D. cannot be determined</p>                                                                                                                                                                           | <p>B. Since the pulse traveled round trip, the total distance is 6 cm.<br/><br/>         For each 13 <math>\mu\text{s}</math>, sound travels a round trip depth of 1 centimeter. Thus, in 39 <math>\mu\text{s}</math>, sound travels to and returns from a depth of 3 cm.</p>                                                                                                                                            |



| Questions                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                                                                                                                            |
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| <p>257. One reflector is 5 times deeper than another. The time of flight of sound to the deeper structure is ____ the time of flight of the shallower reflector.</p> <p>A. one fifth as much as<br/>B. equal to<br/>C. less than<br/>D. five times more than</p>                                                       | <p>D. Time of flight and reflector depth are directly related. When a reflector is five times deeper than another, the pulse's time of flight is five times greater.</p>                                                                                                                           |
| <b>AXIAL RESOLUTION</b>                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                    |
| <p>258. Axial resolution describes the accuracy related to visualizing two structures that are ____ to a sound beam's main axis.</p> <p>A. parallel<br/>B. perpendicular<br/>C. oblique<br/>D. normal</p>                                                                                                              | <p>A. Axial resolution is related to structures that are parallel to the beam's main axis. In other words, the structures are arranged front to back.</p>                                                                                                                                          |
| <p>259. You are purchasing a diagnostic ultrasound system. System X has axial resolution of 0.7 mm whereas System D's is 0.4 mm. Based on this information, which system will produce the better quality picture?</p> <p>A. System X<br/>B. System D<br/>C. they have the same quality<br/>D. cannot be determined</p> | <p>B. Resolution is reported in units of distance, such as cm or mm. Higher image quality is achieved by systems with lower numerical values for resolution.</p> <p>System D has a lower numerical value for longitudinal resolution, and will produce more detailed, higher quality pictures.</p> |
| <p>260. The axial resolution of an imaging system is reported to be 0.85 mm at the beam's focus. What is the closest estimate of the system's radial resolution at a location that is 5 cm deeper than the focus?</p> <p>A. less than 0.85 mm<br/>B. equal to 0.85 mm<br/>C. greater than 0.85 mm</p>                  | <p>B. Radial resolution is determined by the spatial pulse length or the pulse duration. These variables remain constant, regardless of the depth of the pulse.</p> <p>The radial resolution is the same at all imaging depths.</p>                                                                |

| Questions                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                                                                  |
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| <p>261. Two systems are undergoing evaluation. System A has 1,000,000 pixels, each with 4 bits. System B has 750,000 pixels, each with 12 bits. Which system has the best longitudinal resolution?</p> <p>A. System A<br/>B. System B<br/>C. both are the same<br/>D. cannot be determined</p> | <p><b>D.</b> The longitudinal resolution of an ultrasound system is determined primarily by the pulse duration or the spatial pulse length. Since no information is provided on the length of the pulse, it is impossible to determine which of the systems will have superior longitudinal resolution.</p> <p><b>Hint:</b> Longitudinal resolution is also called axial resolution.</p> |
| <p>262. True or False? The lower the numerical value of the longitudinal resolution, the worse the picture.</p>                                                                                                                                                                                | <p><b>False.</b> Higher quality images are associated with lower values of longitudinal resolution. The numerical value indicates how close two structures can be and still produce two distinct images on the ultrasound display. Lower numbers identify ultrasound systems that display images with fine detail.</p>                                                                   |
| <p>263. True or False? One way that a sonographer can alter the axial resolution achieved during an exam is to adjust the maximum imaging depth.</p>                                                                                                                                           | <p><b>False.</b> Depth of view and axial resolution are unrelated. A sonographer cannot adjust imaging depth to change a system's axial resolution.</p>                                                                                                                                                                                                                                  |
| <p>264. True or False? With a specific ultrasound system and transducer, the system's axial resolution is invariant, and the sonographer can do nothing to improve it.</p>                                                                                                                     | <p><b>True.</b> Axial resolution is determined only by the components of the system. When you are using a particular ultrasound system, axial resolution remains constant.</p>                                                                                                                                                                                                           |
| <p>265. True or False? The shorter the pulse duration, the better the picture.</p>                                                                                                                                                                                                             | <p><b>True.</b> This restates one of the fundamental principles of ultrasonic imaging. The shorter the pulse duration, the higher the quality of the images.</p>                                                                                                                                                                                                                         |
| <p>266. An ultrasonic pulse has a pulse repetition period of 1.2 msec, a spatial pulse length of 2.0 mm, and a wavelength of 0.4 mm. What is the axial resolution of the system?</p> <p>A. 2.0 mm<br/>B. 1.0 mm<br/>C. 0.4 mm<br/>D. 1.8 mm</p>                                                | <p><b>B.</b> The axial resolution of an ultrasound system is equal to half of the spatial pulse length produced by the system.</p> <p>In this example, the spatial pulse length is equal to 2.0 mm, and the axial resolution is 1.0 mm.</p> <p>Image accuracy is best when the numerical value of axial resolution is small.</p>                                                         |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
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| <p>267. True or False? The more cycles there are in a pulse, the greater the detail that will be visualized in the ultrasound scan.</p>                                                                                                                                                                                                                                                                                                                                  | <p><b>False.</b> A pulse with many cycles is long. Systems with long pulses cannot produce images with fine detail. When many cycles are in a pulse, less detail is presented on the scans.</p> <p>Transducers with pulses composed of more cycles can be described as "more ringing."</p>                                                                                                                                                                              |
| <p>268. Two ultrasound systems produce acoustic pulses. A pulse from System 1 has a wavelength of 0.5 mm, 4 cycles per pulse, and a pulse repetition period of 1.2 msec. The pulses from System 2 have a wavelength of 1.0 mm, 2 cycles per pulse, and a pulse repetition period of 1.8 msec. Which ultrasound system will have a lower numerical value of axial resolution?</p> <p>A. System 1<br/>B. System 2<br/>C. both are the same<br/>D. cannot be determined</p> | <p><b>C.</b> Range resolution is equal to one-half the spatial pulse length. Spatial pulse length is equal to the number of cycles in the pulse multiplied by the wavelength.</p> <p>System 1's pulse length is <math>4 \times 0.5 \text{ mm} = 2.0 \text{ mm}</math>.</p> <p>System 2's pulse length is <math>2 \times 1.0 \text{ mm} = 2.0 \text{ mm}</math>.</p> <p>Since both systems have identical pulse lengths, their axial resolutions are also identical.</p> |
| <p>269. Which transducer has the best axial resolution?</p> <p>A. 2 cycles/pulse, 4 MHz<br/>B. 4 cycles/pulse, 4 MHz<br/>C. 4 cycles/pulse, 2 MHz<br/>D. 2 cycles/pulse, 2 MHz</p>                                                                                                                                                                                                                                                                                       | <p><b>A.</b> Pulses with the fewest cycles and the highest frequency have the best axial resolution.</p>                                                                                                                                                                                                                                                                                                                                                                |
| <p>270. Which transducer has the worst axial resolution?</p> <p>A. 2 cycles/pulse, 4 MHz<br/>B. 4 cycles/pulse, 4 MHz<br/>C. 4 cycles/pulse, 2 MHz<br/>D. 2 cycles/pulse, 2 MHz</p>                                                                                                                                                                                                                                                                                      | <p><b>C.</b> Pulses with the most cycles and the lowest frequency have the worst axial resolution.</p>                                                                                                                                                                                                                                                                                                                                                                  |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                          |
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| <p>271. Two ultrasound systems produce pulses. One pulse is 0.4 <math>\mu\text{sec}</math> in duration and the other is 0.2 <math>\mu\text{sec}</math> long. Which pulse is most likely to provide the best radial resolution?</p> <p>A. 0.4 <math>\mu\text{sec}</math> system<br/>         B. 0.2 <math>\mu\text{sec}</math> system<br/>         C. they are the same<br/>         D. cannot be determined</p> | <p><b>B.</b> Radial (or axial) resolution is determined by the pulse duration or the spatial pulse length. The shorter the time span that a pulse exists (or the shorter the length of the pulse), the better the radial resolution.</p> <p>The device producing the shorter pulse, 0.2 <math>\mu\text{sec}</math>, has the best radial resolution.</p> <p>Radial resolution is also called axial, depth, longitudinal, or range resolution.</p> |
| <p>272. A sonographer is performing a study on a patient and desires superior depth resolution. Which of the following changes would create such a system?</p> <p>A. higher frequency<br/>         B. shorter wavelength<br/>         C. fewer cycles per pulse<br/>         D. less ringing<br/>         E. all of the above</p>                                                                               | <p><b>E.</b> Systems that produce shorter pulses create better pictures and have lower numerical values for depth resolution. Higher frequency, shorter wavelength, and fewer cycles per pulse all shorten the spatial pulse length, decrease the numerical depth resolution, and create more accurate images.</p>                                                                                                                               |
| <p>273. True or False? The higher the frequency of the cycles within a pulse, the lower the numerical value of the axial resolution.</p>                                                                                                                                                                                                                                                                        | <p><b>True.</b> When traveling through a particular medium, higher frequencies are associated with shorter wavelengths. Shorter wavelengths will shorten the spatial pulse length. Since the axial resolution is equal to one-half the spatial pulse length, the numerical value of the axial resolution will also be reduced.</p>                                                                                                               |
| <p>274. True or False? The shorter the pulse length, the better the picture.</p>                                                                                                                                                                                                                                                                                                                                | <p><b>True.</b> This is the fundamental concept of longitudinal resolution. Shorter pulses produce better pictures.</p> <p>One of the most important design criteria for ultrasound systems and transducers is to minimize the pulse duration and spatial pulse length.</p>                                                                                                                                                                      |

| Questions                                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                               |
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| <b>TRANSDUCERS</b>                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                       |
| <p>275. Which component of an ultrasound system is made of lead zirconate titanate (PZT)?</p> <ul style="list-style-type: none"> <li>A. transducer's matching layer</li> <li>B. transducer's active element</li> <li>C. transducer's damping material</li> <li>D. scan converter's computer chips</li> </ul>                                    | <p><b>B.</b> Lead zirconate titanate, abbreviated PZT, is a man-made piezoelectric material commonly used as the active element of ultrasound transducers.</p>                                                                        |
| <p>276. How thick is the active element of a 3 MHz pulsed wave transducer?</p> <ul style="list-style-type: none"> <li>A. 1.54 mm</li> <li>B. 0.51 mm</li> <li>C. half the wavelength of the sound wave in the PZT</li> <li>D. one-quarter the wavelength of sound in the matching layer</li> </ul>                                              | <p><b>C.</b> The PZT is half a wavelength thick. That is, the thickness is equal to one-half the wavelength of sound in the PZT.</p>                                                                                                  |
| <p>277. True or False? The purpose of the backing material of an ultrasound transducer is to shorten the pulses, thereby creating images with better image quality.</p>                                                                                                                                                                         | <p><b>True.</b> Diagnostic imaging transducers are especially effective in creating excellent images when their pulses are short. The backing material reduces the ringing of the active element and shortens the pulse duration.</p> |
| <p>278. The main purposes of a transducer's case are (more than one may be correct):</p> <ul style="list-style-type: none"> <li>A. to protect the patient from shock</li> <li>B. to protect the patient from heat</li> <li>C. to protect the internal components of the transducer</li> <li>D. to protect the patient from radiation</li> </ul> | <p><b>A and C.</b> The case of a transducer protects the patient from electrical shock and also protects the internal components of the transducer from damage.</p>                                                                   |
| <p>279. Which component of an ultrasound transducer is made from a slab of epoxy embedded with tungsten particles?</p> <ul style="list-style-type: none"> <li>A. the matching layer</li> <li>B. the piezoelectric crystal</li> <li>C. the damping material</li> <li>D. the computer chips</li> </ul>                                            | <p><b>C.</b> The backing material, or damping material, of a transducer assembly is often fabricated of tungsten-embedded epoxy.</p>                                                                                                  |

| Questions                                                                                                                                                                                                                                                                                                                  | Answers                                                                                                                                                                                                                                                                                                                                                                                                                     |
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| <p>280. True or False? The characteristic impedance of acoustic gel is greater than the matching layer's impedance but less than the piezoelectric element's impedance.</p>                                                                                                                                                | <p><b>False.</b> The acoustic impedance of gel is lower than the impedances of both the active element and the matching layer. The gel increases the efficiency of sound transmission at the transducer/skin boundary. Consequently, the gel must have an impedance that is between those of the matching layer and the skin.</p>                                                                                           |
| <p>281. The impedance of a transducer's matching layer is 2.6 MRayls and the impedance of the piezoelectric crystal is 3.4 MRayls. If this is assumed to be a good imaging system, what is the best estimate for the impedance of the skin?</p> <p>A. 1.5 MRayls<br/>B. 3.8 MRayls<br/>C. 3.4 MRayls<br/>D. 2.8 MRayls</p> | <p><b>A.</b> The impedance of a transducer's matching layer should be between the impedance of skin and the impedance of the piezoelectric crystal.</p>                                                                                                                                                                                                                                                                     |
| <p>282. True or False? The piezoelectric crystal of a transducer typically has an impedance higher than the impedance of skin.</p>                                                                                                                                                                                         | <p><b>True.</b> The impedance of piezoelectric crystals typically exceeds the impedance of skin. To calculate impedance, multiply the density of a material by the propagation speed of the material. The density of lead zirconate titanate (a common piezoelectric material) is greater than the density of skin. The propagation speeds of piezoelectric crystals are usually three to four times greater than skin.</p> |
| <p>283. Which of the following lists orders the impedance from highest to lowest?</p> <p>A. skin, gel, matching layer, PZT<br/>B. PZT, gel, matching layer, skin<br/>C. gel, PZT, matching layer, skin<br/>D. PZT, matching layer, gel, skin</p>                                                                           | <p><b>D.</b> To maximize the transmission of sound energy between the transducer and the body, the impedances of the active element, matching layer, gel, and skin must be in decreasing order. The impedance of the piezoelectric crystal is the highest, the matching layer's impedance is a bit lower, the gel's impedance is lower yet, and the impedance of the skin is the lowest of all.</p>                         |



| Questions                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                           |
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| <p>284. What is the thickness of the matching layer of a 2 MHz pulsed wave transducer?</p> <p>A. 1.54 mm<br/>B. 0.77 mm<br/>C. half the wavelength of the sound wave in the PZT<br/>D. one-quarter the wavelength of sound in the matching layer</p> | <p><b>D.</b> The matching layer is one-quarter wavelength thick. That is, the thickness is equal to one-quarter the wavelength of sound in the matching layer.</p>                                                                                                                                |
| <p>285. True or False? The acoustic impedance of the skin is greater than the acoustic impedances of both the matching layer and the piezoelectric element.</p>                                                                                      | <p><b>False.</b> The acoustic impedance of the skin is lower than the impedances of both the matching layer and the piezoelectric crystal.</p>                                                                                                                                                    |
| <p>With regard to the backing material of a pulsed ultrasound transducer, are the following 5 statements true or false?</p>                                                                                                                          |                                                                                                                                                                                                                                                                                                   |
| <p>286. The damping material helps to decrease the pulse repetition period achieved at a given imaging depth.</p>                                                                                                                                    | <p><b>False.</b> The pulse repetition period (PRP) is the time from the start of one pulse to the start of the subsequent pulse. The pulse repetition period is determined by the maximum imaging depth established by the sonographer. PRP is unrelated to the presence of backing material.</p> |
| <p>287. The backing material helps to decrease the duty cycle at a particular PRF.</p>                                                                                                                                                               | <p><b>True.</b> The backing material of an imaging transducer tends to shorten the pulse duration. This decreases the percentage of time that the system is "talking" and therefore decreases the duty factor.</p>                                                                                |
| <p>288. The pulse duration is increased as a result of the presence of backing material.</p>                                                                                                                                                         | <p><b>False.</b> The backing material inhibits the crystal's oscillations and shortens the pulse duration. When a ferroelectric crystal does not have backing material, it can vibrate freely and ring for a long time.</p>                                                                       |
| <p>289. The backing material decreases the quality factor.</p>                                                                                                                                                                                       | <p><b>True.</b> The backing material that is attached to the back of the piezoelectric crystal will decrease the transducer's Q-factor.</p>                                                                                                                                                       |

| Questions                                                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
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| <p>290. The spatial pulse length is decreased with the application of backing material.</p>                                                                                                                                                                                                                               | <p><b>True.</b> The backing material tends to diminish the "ringing" of the transducer's active element after it is excited by the electrical signal from the pulser. This shortens the pulse length. The action of the damping material is similar to the action of a cymbal player in a band. If a short tone is desired, the musician pinches the cymbals between his arms and ribs. This stops the cymbals from vibrating and shortens the spatial pulse length. The terms backing material and damping material are synonymous.</p> |
| <p>291. Assume that the frequency of sound with the greatest power emitted by a transducer is 5 MHz. However, the pulse contains acoustic energy with frequencies as low as 3.5 MHz and as high as 6.5 MHz. What is the bandwidth of the transducer?</p> <p>A. 6.5 MHz<br/>B. 5.0 MHz<br/>C. 3.5 MHz<br/>D. 3.0 MHz</p>   | <p><b>D.</b> The bandwidth of a pulse is defined as the range of frequencies that are present within the pulse. To calculate bandwidth, subtract the lowest frequency from the highest frequency in the acoustic signal (<math>6.5 - 3.5 = 3.0</math> MHz). The bandwidth is 3.0 MHz. The natural or center frequency of this transducer is 5 MHz.</p>                                                                                                                                                                                   |
| <p>292. True or False? In general, ultrasound imaging transducers have a lower quality factor and a wider bandwidth than therapeutic ultrasound transducers.</p>                                                                                                                                                          | <p><b>True.</b> Diagnostic imaging transducers have a lower quality factor than therapeutic ultrasound transducers. The backing material acts to shorten the pulse, but concurrently increases the bandwidth and decreases the Q-factor.</p>                                                                                                                                                                                                                                                                                             |
| <p>293. Damping material is secured to piezoelectric material during the fabrication of an ultrasonic imaging transducer. Which of the following is not a consequence of this attachment?</p> <p>A. bandwidth increases<br/>B. quality factor decreases<br/>C. sensitivity increases<br/>D. transducer case is longer</p> | <p><b>C.</b> The damping material of an imaging transducer decreases the transducer's sensitivity.</p> <p>The backing material increases bandwidth, decreases the Q-factor, and lengthens the transducer case.</p>                                                                                                                                                                                                                                                                                                                       |

| Questions                                                                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                                       |
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| <p>294. Which of the following actions would cause a PZT crystal to lose its special properties?</p> <ul style="list-style-type: none"> <li>A. breaking it in pieces</li> <li>B. exposing it to high temperatures</li> <li>C. exposing it to electrical current</li> <li>D. exposing it to low pressures</li> </ul>                                                                              | <p><b>B.</b> When a piezoelectric crystal is exposed to high temperatures, it will <i>depolarize</i> and permanently lose its piezoelectric properties.</p> <p>This temperature is known as the Curie temperature or Curie point.</p> <p><b>B</b></p>                                                                                                         |
| <p>295. All of the following are true about transducers <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. it is necessary to sterilize transducers before use</li> <li><b>B. most transducers simply require disinfection as they do not penetrate mucous membranes</b></li> <li>C. sterilization could depolarize PZT</li> <li>D. they are unlikely to transmit infection</li> </ul> | <p><b>A.</b> Generally, it is unnecessary to sterilize most ultrasound transducers since they do not penetrate mucous membranes. Typically, simple disinfection is all that is needed.</p>                                                                                                                                                                    |
| <p>296. Which properties of the piezoelectric crystal of a continuous wave transducer result in the highest emitted acoustic wave frequency?</p> <ul style="list-style-type: none"> <li>A. thin, high propagation speed</li> <li>B. thick, slow propagation speed</li> <li>C. thin, slow propagation speed</li> <li>D. none of the above</li> </ul>                                              | <p><b>D.</b> The frequency of sound emitted by a continuous wave transducer is determined only by the frequency of the electrical signal that excites the piezoelectric crystal. The crystal's thickness and propagation speed do not affect the frequency of sound from a continuous wave transducer.</p>                                                    |
| <p>297. What helps to determine the frequency of the sound produced by the transducer of a continuous wave ultrasound system?</p> <ul style="list-style-type: none"> <li>A. piezoelectric crystal diameter</li> <li>B. piezoelectric crystal thickness</li> <li>C. damping material density</li> <li>D. ultrasound system electronics</li> </ul>                                                 | <p><b>D.</b> A continuous wave (CW) transducer produces an acoustic wave with a frequency equal to the frequency of the electrical signal that excites the crystal. When the pulser's electrical signal has a frequency of 6 MHz, then the emitted acoustic wave is also 6 MHz. The electronics of a CW system determine the frequency of the sound wave.</p> |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                                                          |
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| <p>298. With pulsed wave ultrasonic imaging, what helps to establish the primary frequency of the acoustic energy discharged by the transducer?</p> <ul style="list-style-type: none"> <li>A. piezoelectric crystal diameter</li> <li>B. piezoelectric crystal thickness</li> <li>C. damping material density</li> <li>D. ultrasound system electronics</li> </ul>                                                                                                                  | <p>B. The frequency of sound produced by a standard pulsed wave imaging instrument is partly determined by the thickness of the piezoelectric element. Just as different tones are produced when a musician plays different bars on a xylophone, piezoelectric crystals of various thicknesses produce acoustic pulses of different frequencies.</p>                                                                             |
| <p>299. An ultrasonic pulse is traveling in soft tissue. Which of the following is most important in the determination of the frequency of the sound?</p> <ul style="list-style-type: none"> <li>A. the propagation speed of the ultrasound transducer's matching layer</li> <li>B. the thickness of the transducer's backing material</li> <li>C. the impedance of the transducer's matching layer</li> <li>D. the propagation speed of the transducer's active element</li> </ul> | <p>D. The two characteristics that determine the frequency of sound in a pulse are:</p> <ol style="list-style-type: none"> <li>1. the thickness of the ultrasound crystal and</li> <li>2. the propagation speed of the crystal.</li> </ol> <p>The speed and impedance of the matching layer and the thickness of the backing material are unrelated to the frequency of an ultrasound pulse.</p>                                 |
| <p>300. What is the best estimate of the propagation speed of the ferroelectric element of a transducer used in a typical diagnostic imaging laboratory?</p> <ul style="list-style-type: none"> <li>A. 1.2 mm/<math>\mu</math>sec</li> <li>B. 4.0 m/sec</li> <li>C. 4.0 mm/<math>\mu</math>sec</li> <li>D. 1.0 km/sec</li> </ul>                                                                                                                                                    | <p>C. The active element of a typical diagnostic imaging transducer has a propagation speed that is approximately three to five times greater than the speed of ultrasound through soft tissue. This range is approximately <u>4 to 8 km/sec</u>. Other ways of stating this are 4 to 8 mm/<math>\mu</math>sec, or 4,000 to 8,000 m/sec. Choices A, B, and D are all too low to be the speed of sound in an imaging crystal.</p> |
| <p>301. Which properties of the piezoelectric crystal of an imaging transducer result in the highest emitted acoustic wave frequency?</p> <ul style="list-style-type: none"> <li>A. thin, high propagation speed</li> <li>B. thick, slow propagation speed</li> <li>C. thin, slow propagation speed</li> <li>D. none of the above</li> </ul>                                                                                                                                        | <p>A. Only pulsed wave transducers can create images. The crystal's thickness and propagation speed determine the frequency of sound created by these transducers.</p> <p>Highest frequency sound is created by thin crystals in which sound travels quickly.</p>                                                                                                                                                                |

high frequency  
thin  $\downarrow$   
high propagation  $\uparrow$

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
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| <p>302. You are asked to fabricate a pulsed ultrasound transducer with the highest possible frequency. Which piezoelectric crystal would you select?</p> <ul style="list-style-type: none"> <li>A. 6 mm thick, 4 cm diameter, 4.0 mm/<math>\mu</math>s propagation speed</li> <li>B. 8 mm thick, 2 cm diameter, 6.0 mm/<math>\mu</math>s propagation speed</li> <li>C. 4 mm thick, 9 cm diameter, 5.0 mm/<math>\mu</math>s propagation speed</li> <li>D. 2 mm thick, 6 cm diameter, 6.0 mm/<math>\mu</math>s propagation speed</li> </ul> | <p>D. The main frequency (also called resonant, natural, or center frequency) emitted by a piezoelectric crystal operating in the pulsed mode is principally determined by the thickness and propagation speed of the crystal. The frequency is greater when the crystal is thin and its propagation speed is high, so the active element listed in D is the proper choice. The diameter of the active element does not affect the frequency of the pulse.</p> |
| <p>303. You are asked to fabricate a pulsed ultrasound transducer with the lowest possible frequency. Which piezoelectric crystal would you select?</p> <ul style="list-style-type: none"> <li>A. 6 mm thick, 4 cm diameter, 4.0 mm/<math>\mu</math>s propagation speed</li> <li>B. 8 mm thick, 2 cm diameter, 2.0 mm/<math>\mu</math>s propagation speed</li> <li>C. 4 mm thick, 9 cm diameter, 5.0 mm/<math>\mu</math>s propagation speed</li> <li>D. 2 mm thick, 6 cm diameter, 6.0 mm/<math>\mu</math>s propagation speed</li> </ul>  | <p>B. The frequency is lowest when the crystal is thick and its propagation speed is low, so the active element listed in B is the proper choice. The diameter of the active element does not affect the frequency of the pulse.</p>                                                                                                                                                                                                                           |
| <b>SOUND BEAMS</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <p>304. What is the region from the transducer to the smallest cross-sectional area of a sound beam called?</p> <ul style="list-style-type: none"> <li>A. focus</li> <li>B. half-value thickness</li> <li>C. near zone</li> <li>D. Fraunhofer zone</li> </ul>                                                                                                                                                                                                                                                                             | <p>C. The region from the transducer to the narrowest portion of an ultrasound beam is defined as the near zone, or Fresnel zone.</p>                                                                                                                                                                                                                                                                                                                          |
| <p>305. The area that starts at the beam's smallest diameter and extends deeper is:</p> <ul style="list-style-type: none"> <li>A. the distant zone</li> <li>B. the Fresnel zone</li> <li>C. the Fraunhofer zone</li> <li>D. the depth of penetration</li> </ul>                                                                                                                                                                                                                                                                           | <p>C. The region that extends deeper from an ultrasound beam's narrowest diameter and deeper is called the far zone, or Fraunhofer zone.</p>                                                                                                                                                                                                                                                                                                                   |

| Questions                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                          |
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| <p>306. Which of these terms have the same meaning?</p> <p>1) far zone                      2) near zone<br/>3) Fresnel zone                4) focal zone<br/>5) Fraunhofer zone          6) lateral zone</p> <p>A. 1 and 2, 3 and 4<br/>B. 1 and 4, 2 and 3<br/>C. 4 and 6, 5 and 1<br/>D. 2 and 3, 5 and 1</p> | <p>D. Another name for the Fresnel zone is the near zone. The Fraunhofer zone can also be called the far zone.</p> <p>(Hint: Fresnel is the short name—it is the near zone. Fraunhofer is the long name—it is the far zone.)</p> |
| <p>307. What is the point or location where a beam reaches its smallest dimension?</p> <p>A. near zone<br/>B. focus<br/>C. penetration depth<br/>D. focal zone</p>                                                                                                                                               | <p>B. The actual location where an ultrasound beam reaches its minimum diameter and cross-sectional area is called the focus.</p>                                                                                                |
| <p>308. All of the following are true of the focus <i>except</i>:</p> <p>A. it is at the end of the near zone<br/>B. it is at the beginning of the Fraunhofer zone<br/>C. it has the highest spatial peak intensity<br/>D. it is at the start of the Fresnel zone</p>                                            | <p>D. The focus is located at the end of the near or Fresnel zone. The Fresnel zone starts at the transducer.</p>                                                                                                                |



| Questions                                                                                                                                                             | Answers                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>A PZT crystal in the shape of a disc produces a continuous ultrasound wave. The beam is unfocused. Are the following 9 statements true or false?</p>               |                                                                                                                                                                                   |
| <p>309. The near zone is the only region where the diameter of the sound beam is smaller than the transducer's.</p>                                                   | <p><b>False.</b> The sound beam created by a disc-shaped continuous wave crystal is smaller than the crystal in the near zone and the initial part of the far zone.</p>           |
| <p>310. The far zone is the only region where the beam diameter exceeds the transducer diameter.</p>                                                                  | <p><b>True.</b> Beam diameter exceeds transducer diameter only in the far zone, never in the near zone.</p>                                                                       |
| <p>311. If the diameter of a sound beam is 8 mm at a depth equal to twice the near zone length, then the PZT crystal has a diameter of 16 mm.</p>                     | <p><b>False.</b> When a continuous wave is produced by a disc-shaped crystal, the beam's diameter equals the crystal's diameter at a depth of twice the near zone length.</p>     |
| <p>312. If the diameter of the acoustic beam produced by a crystal is 8 mm at a depth of twice the near zone length, then the PZT crystal has a diameter of 8 mm.</p> | <p><b>True.</b> When a continuous wave is produced by a disc-shaped crystal, the beam's diameter equals the crystal's diameter at a depth that is twice the near zone length.</p> |
| <p>313. The near zone is the only region where the diameter of the sound beam decreases as depth increases.</p>                                                       | <p><b>True.</b> In the near zone, the sound beam actually tapers down until it reaches the focus. At depths greater than the near zone, the beam diverges, or spreads out.</p>    |
| <p>314. If the narrowest diameter of a sound beam is at a depth of 8 cm, then the PZT crystal's diameter is 16 cm.</p>                                                | <p><b>False.</b> The depth of the focus is not determined solely by the diameter of the piezoelectric crystal producing it.</p>                                                   |
| <p>315. The higher the frequency of the acoustic wave, the shorter the length of the near zone.</p>                                                                   | <p><b>False.</b> The focus gets deeper as the frequency of the wave increases. With low frequency sound, the focus is shallower.</p>                                              |
| <p>316. The greater the diameter of a transducer's piezoelectric crystal, the longer the near zone length is.</p>                                                     | <p><b>True.</b> Large diameter crystals tend to produce continuous wave sound beams with a deeper focus. The beam's near zone is longer.</p>                                      |
| <p>317. The thicker a continuous wave transducer's piezoelectric crystal, the longer the near zone length is.</p>                                                     | <p><b>False.</b> Increasing the thickness of a piezoelectric crystal does not alter the length of the near zone of a continuous wave ultrasound beam.</p>                         |

| Questions                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                             |
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| <p>318. For a disc-shaped PZT crystal producing continuous sound, which design will create a beam with the shallowest focus?</p> <p>A. large diameter, low frequency<br/>         B. large diameter, high frequency<br/>         C. small diameter, low frequency<br/>         D. small diameter, high frequency</p>                                                | <p>C. A continuous wave transducer producing the shortest near zone (the most shallow focus) will have a small diameter and a low emitted frequency.</p>                                                                                                            |
| <p>319. For a disc-shaped PZT crystal producing continuous sound, which design will create a beam with the deepest focus?</p> <p>A. large diameter, low frequency<br/>         B. large diameter, high frequency<br/>         C. small diameter, low frequency<br/>         D. small diameter, high frequency</p>                                                   | <p>B. A continuous wave transducer producing the longest near zone (the deepest focus) will have a large diameter and a high frequency.</p>                                                                                                                         |
| <p>320. Two ultrasound systems are identical except for the diameter of the transducer's piezoelectric crystal. Which system has the deepest focus?</p> <p>A. the system with the smaller diameter crystal<br/>         B. the one with the larger diameter crystal<br/>         C. their foci will be at the same depth</p>                                        | <p>B. Large diameter crystals tend to produce ultrasound beams with more distant foci. The larger the crystal diameter, the deeper the focus. Smaller diameter crystals produce beams with shallower foci.</p>                                                      |
| <p>321. Two systems are identical except for the frequency of the emitted pulse. Which system will have the deeper focus?</p> <p>A. the lower frequency system<br/>         B. the higher frequency system<br/>         C. both foci will be at the same depth</p>                                                                                                  | <p>B. High frequency piezoelectric crystals tend to produce ultrasound beams with deeper foci.</p> <p>Frequency and focal depth are directly related. Higher acoustic frequencies create deeper foci. Lower frequency crystals produce beams with shallow foci.</p> |
| <p>322. As sound travels deeply into the far zone, the beam diverges, or spreads out. Which of the following will result in a minimum beam divergence deep in the far zone?</p> <p>A. small diameter, high frequency<br/>         B. high frequency, large diameter<br/>         C. large diameter, low frequency<br/>         D. low frequency, small diameter</p> | <p>B. Large diameter crystals of high frequency tend to produce sound beams that diverge less in the deep far zone.</p> <p>In contrast, waves from small diameter, low frequency crystals are more divergent in the deep far zone.</p>                              |



| Questions                                                                                                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                         |
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| <p>323. As sound travels deeply into the far zone, the beam diverges, or spreads out. Which will result in the greatest beam divergence deep in the far zone?</p> <ul style="list-style-type: none"> <li>A. small diameter, high frequency</li> <li>B. high frequency, large diameter</li> <li>C. large diameter, low frequency</li> <li>D. low frequency, small diameter</li> </ul> | <p>D. Small diameter crystals of low frequency tend to produce sound beams that diverge most in the deep far zone.</p>                                                                                                          |
| <p>324. Two ultrasound systems are identical except for the pulse repetition period (PRP) of the emitted pulse. Which system will have the deeper focus?</p> <ul style="list-style-type: none"> <li>A. the system with the lower PRP</li> <li>B. the system with the higher PRP</li> <li>C. their foci will be at the same depth</li> </ul>                                          | <p>C. Changes in the pulse repetition period do not affect the depth of the focus. The frequency of the sound and the piezoelectric crystal's diameter help to determine the focal depth.</p>                                   |
| <p>325. All of the following terms describe the shape of a sound wave created by a tiny fragment of PZT <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. spherical</li> <li>B. Huygens' wavelet</li> <li>C. V-shaped</li> <li>D. hourglass shaped</li> </ul>                                                                                                             | <p>D. The waves are not hourglass in shape. Small pieces of PZT create V-shaped waves. Choices A and B have the same meaning as V-shaped.</p>                                                                                   |
| <p>326. Which of the following explains the difference in sound beam shape created by a disc-shaped crystal from that of a small chip of PZT?</p> <ul style="list-style-type: none"> <li>A. Huygens' Principle</li> <li>B. Snell's Law</li> <li>C. Bernoulli's Law</li> <li>D. Murphy's Law</li> </ul>                                                                               | <p>A. Huygens' Principle explains the difference between the beam shape from tiny chips of PZT and disc crystals of a larger dimension.</p>                                                                                     |
| <p>327. Huygens' Principle is based on ____.</p> <ul style="list-style-type: none"> <li>A. refraction</li> <li>B. constructive indices</li> <li>C. transverse waves</li> <li>D. interference</li> </ul>                                                                                                                                                                              | <p>D. Huygens' Principle explains the difference between the beam shape from tiny pieces of PZT and disc crystals of a larger dimension.</p> <p>The hourglass-shaped beam is caused by the interference of spherical waves.</p> |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                           |
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| <b>LATERAL RESOLUTION and FOCUSING</b>                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                   |
| <p>328. The focus of an ultrasound beam is the location where the ____.</p> <ol style="list-style-type: none"> <li>beam is the broadest</li> <li>optimum transverse resolution is</li> <li>frequency is the highest</li> <li>finest depth resolution is obtained</li> </ol>                                                                                                                                                          | <p><b>B.</b> The focus of an ultrasound beam is the location where the beam is most narrow. The narrowest portion of the beam provides the optimal transverse or lateral resolution.</p>                          |
| <p>329. The lateral resolution of an ultrasound system is primarily determined by the ____.</p> <ol style="list-style-type: none"> <li>width of the sound pulse</li> <li>length of the ultrasound pulse</li> <li>duration of the sound pulse</li> <li>none of the above</li> </ol>                                                                                                                                                   | <p><b>A.</b> The lateral resolution achieved by an imaging system is approximately equal to the width of the ultrasound pulse.</p>                                                                                |
| <p>330. Two ultrasound systems produce acoustic pulses. One pulse is 0.4 <math>\mu\text{sec}</math> in duration and the other is 0.2 <math>\mu\text{sec}</math>. Which pulse will most likely provide the best lateral resolution?</p> <ol style="list-style-type: none"> <li>0.4 <math>\mu\text{sec}</math> pulse</li> <li>0.2 <math>\mu\text{sec}</math> pulse</li> <li>they are the same</li> <li>cannot be determined</li> </ol> | <p><b>D.</b> The duration of a pulse is unrelated to the lateral resolution. Pulse duration affects axial (longitudinal) resolution. It is not possible to answer the question with the information provided.</p> |
| <p>331. True or False? The pulse duration does not profoundly influence the lateral resolution.</p>                                                                                                                                                                                                                                                                                                                                  | <p><b>True.</b> Generally, the primary determinant of lateral resolution is the sound beam's diameter. The pulse length, or duration, does not dramatically alter the lateral resolution.</p>                     |
| <p>332. Two ultrasound systems have near zone lengths of 8 cm. At the focus, System G's lateral resolution is 3.0 mm, whereas System P's is 5.0 mm. Which system will produce higher quality pictures at their foci?</p> <ol style="list-style-type: none"> <li>System P</li> <li>System G</li> <li>both will be of similar quality</li> </ol>                                                                                       | <p><b>B.</b> Since System G has a narrower beam than System P at the end of the near field (which is the location of the foci), System G will produce higher quality images at that depth.</p>                    |

| Questions                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                                                               |
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| <p>333. True or False? When using standard ultrasonic imaging instrumentation, the lateral resolution has a higher numerical value than the axial resolution.</p>                                                                                                                                                                                                   | <p><b>True.</b> Most imaging systems have better axial resolution than lateral resolution. The lateral resolution will have a higher numerical value than the axial resolution because a sound pulse is typically wider than half its length.</p>                                                                                                                                                                                     |
| <p>334. Two ultrasound systems have near zone lengths of 8 cm. At their foci, System Q's lateral resolution is 3.0 mm and System H's is 5.0 mm. Which system will correctly display two small structures at a depth of 8 cm? The objects are side by side and are 0.4 cm apart.</p> <p>A. System H<br/>B. System Q<br/>C. both produce similar quality pictures</p> | <p><b>B.</b> At a depth of 8 cm, System Q will produce a more accurate picture of two structures that are 0.4 cm apart. A system's lateral resolution is approximated by the beam diameter at that depth. System Q's beam diameter is 3.0 mm at its focus and will display this pair of reflectors accurately. System H's beam, with a diameter of 5 mm, is too wide to display this pair of reflectors as distinct and separate.</p> |
| <p>335. The lateral resolution of an ultrasound system is 4 mm. Two structures are separated by 3 mm and lie side by side in relation to the sound beam's main axis. What will most likely appear on the system's display?</p> <p>A. two weak echoes, 4 mm apart<br/>B. two bright echoes, 3 mm apart<br/>C. one echo<br/>D. two bright echoes, 7 mm apart</p>      | <p><b>C.</b> When two structures are closer together than the resolution of an ultrasound system, the images of the structures will blur together. Since these structures are 3 mm apart and the lateral resolution is 4 mm, only a single echo representing both reflectors will appear on the image.</p>                                                                                                                            |
| <p>336. True or False? When using an instrument typical of today's imaging devices, a higher frequency transducer is likely to mildly improve the system's lateral resolution.</p>                                                                                                                                                                                  | <p><b>True.</b> With all other variables being equal, pulses made with higher frequency sound are somewhat narrower than low frequency pulses. Narrow beams improve the lateral resolution of the imaging system.</p>                                                                                                                                                                                                                 |
| <p>337. True or False? When using an instrument typical of today's diagnostic imaging devices, a higher frequency transducer is likely to improve the axial resolution.</p>                                                                                                                                                                                         | <p><b>True.</b> Higher frequency ultrasound pulses typically have shorter pulse lengths. Short pulse lengths correspond to images with good range resolution.</p>                                                                                                                                                                                                                                                                     |

| Questions                                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                    |
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| <p>338. What will lower the value of an ultrasound system's lateral resolution?</p> <ul style="list-style-type: none"> <li>A. decrease the # of cycles in the pulse</li> <li>B. increase the effective damping material</li> <li>C. increase the pulse repetition period</li> <li>D. use an acoustic lens</li> </ul> | <p>D. To lower the numerical value of lateral resolution of an ultrasound system, the diameter of the beam must be reduced. A commonly used technique to decrease the diameter of the beam is to focus the beam with an acoustic lens.</p> |
| <p>339. Which of the following focusing techniques is different from the others?</p> <ul style="list-style-type: none"> <li>A. lens</li> <li>B. curved crystal</li> <li>C. fixed</li> <li>D. phased</li> </ul>                                                                                                       | <p>D. Phased focusing is achieved with the electronics of an ultrasound system. Phased focusing is adjustable. Focusing with either a lens or curved crystal is fixed.</p>                                                                 |
| <p>340. Which of the following techniques is internal focusing?</p> <ul style="list-style-type: none"> <li>A. lens</li> <li>B. curved crystal</li> <li>C. electronic</li> </ul>                                                                                                                                      | <p>B. Focusing with a curved PZT crystal is known as internal focusing.</p>                                                                                                                                                                |
| <p>341. Which of the following techniques is external focusing?</p> <ul style="list-style-type: none"> <li>A. lens</li> <li>B. curved crystal</li> <li>C. electronic</li> </ul>                                                                                                                                      | <p>A. Focusing with a lens is known as external focusing.</p>                                                                                                                                                                              |
| <p>342. Which of these terms means adjustable focusing or multi-focusing?</p> <ul style="list-style-type: none"> <li>A. dynamic aperture</li> <li>B. harmonics</li> <li>C. frequency agility</li> <li>D. phased array</li> </ul>                                                                                     | <p>D. All phased array transducers share one of these two features:</p> <ol style="list-style-type: none"> <li>1. they have multi-focus capabilities or</li> <li>2. the focal depth can be changed by the sonographer.</li> </ol>          |
| <p>343. Which of these techniques is consistent with variable or multi-focusing?</p> <ul style="list-style-type: none"> <li>A. lens</li> <li>B. curved crystal</li> <li>C. electronic</li> </ul>                                                                                                                     | <p>C. Electronic focusing is achieved with phasing of electronic signals. Electronic focusing, unlike internal or external focusing, is adjusted by the sonographer. In addition, it is multi-focus.</p>                                   |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                                                                                                       |
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| <p>344. All of the following occur with focusing <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. lower intensity at the focus</li> <li>B. shorter near zone length</li> <li>C. more compact focal zone</li> <li>D. smaller diameter beam diameter at the end of the near zone</li> </ul>                                                                                                                                                                 | <p><b>A.</b> Focusing does not lower the beam's intensity at the focus. With focusing, the near zone is shallower, the focal zone is smaller, and the beam is narrower at the focus.</p>                                                                                                                                                                                                                      |
| <p>345. In which region of a sound beam is focusing most effective?</p> <ul style="list-style-type: none"> <li>A. the very shallow near zone</li> <li>B. the end of the near zone</li> <li>C. very deep in the far zone</li> <li>D. throughout its entire length</li> </ul>                                                                                                                                                                                           | <p><b>B.</b> The region of a beam that is most affected by focusing is close to the end of the near zone and at the beginning of the far zone. This region is called the focal zone.</p>                                                                                                                                                                                                                      |
| <p>346. True or False? In comparison to other locations along the length of an ultrasound beam, focusing is generally ineffective in the far zone.</p>                                                                                                                                                                                                                                                                                                                | <p><b>True.</b> Focusing is a technique that narrows the width of a sound beam to improve image quality. When a beam undergoes focusing, it narrows in the region in the focal zone but not in the deep far zone.</p>                                                                                                                                                                                         |
| <p>347. Two ultrasound systems have near zone lengths of 8 cm. At the focus, System S's lateral resolution is 3.0 mm, whereas System C's is 5.0 mm. Which system is most likely to appropriately display two small body structures that lie, one in front of the other, at depths of 8.6 and 9.0 mm?</p> <ul style="list-style-type: none"> <li>A. System C</li> <li>B. System S</li> <li>C. both have comparable quality</li> <li>D. cannot be determined</li> </ul> | <p><b>D.</b> There is insufficient information to answer the question. The information provided gives insight into the lateral resolution of the systems.</p> <p>However, the question asks about the ability to distinguish two structures that lie one in front of the other, or parallel to the sound beam's main axis. This depends upon axial resolution, and no information is provided about this.</p> |
| <p>348. The diameter of a disc-shaped, unfocused piezoelectric crystal is 1 cm. What is the best estimate for the minimum lateral resolution of the ultrasound system?</p> <ul style="list-style-type: none"> <li>A. 1 mm</li> <li>B. 5 mm</li> <li>C. 1 cm</li> <li>D. 5 cm</li> </ul>                                                                                                                                                                               | <p><b>B.</b> Generally, unfocused sound beams produced by a disc-shaped crystal have an hourglass shape. The beam tapers to a minimum diameter at the focus. At the focus, the beam diameter is approximately one-half the diameter of the PZT crystal. In this example, the minimum beam diameter is 5 mm, and this represents the lateral resolution of the system.</p>                                     |

| Questions                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
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| <p>349. The diameter of a disc-shaped, unfocused piezoelectric crystal is 1.2 cm. The near zone length is 8 cm. What is the best estimate for the lateral resolution at a depth of 16 cm?</p> <p>A. 0.6 cm<br/>B. 1.2 cm<br/>C. 8 cm<br/>D. 16 cm</p> | <p>B. Generally, unfocused sound beams produced by a disc-shaped crystal have a profile where the beam tapers to a minimum diameter at the focus and then starts to diverge. At a distance of twice the near zone length, the beam diameter is approximately equal to the piezoelectric crystal diameter. The beam diameter at a depth of 16 cm (which is twice the near zone length) is equal to the crystal diameter, 1.2 cm. Thus, 1.2 cm is the lateral resolution at that depth.</p> |
| DISPLAY MODES                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <p>350. Which imaging modality places time-of-flight information on the x-axis and echo amplitude on the y-axis?</p> <p>A. M-mode      B. L-mode<br/>C. J-mode      D. A-mode</p>                                                                     | <p>D. A-mode, or amplitude mode, displays reflector depth on the x-axis. Reflector depth is determined by a pulse's time of flight. The strength of the reflection is displayed on the y-axis.</p>                                                                                                                                                                                                                                                                                        |
| <p>351. Which imaging mode accurately displays reflector depth?</p> <p>A. I-mode      B. L-mode<br/>C. C-mode      D. A-mode</p>                                                                                                                      | <p>D. A-mode, or amplitude mode, displays the reflector depth accurately. A-mode is used in ophthalmology, which requires precise measures of depth or thickness.</p>                                                                                                                                                                                                                                                                                                                     |
| <p>352. Which imaging technique usually displays a single jagged line of varying heights?</p> <p>A. A-mode<br/>B. B-mode<br/>C. C-mode<br/>D. I-mode</p>                                                                                              | <p>A. A-mode displays reflected echoes as spikes of varying height. Echo amplitude appears on the y-axis, and reflector depth on the x-axis. The spike's location on the x-axis is based on the pulse's time of flight. The height of the peak is determined by the reflection's strength. Stronger reflections create higher spikes.</p>                                                                                                                                                 |
| <p>353. With B-mode, on which axis is the strength of the reflection input?</p> <p>A. x-axis<br/>B. y-axis<br/>C. z-axis</p>                                                                                                                          | <p>C. With B-mode, reflection strength is input into the z-axis.</p>                                                                                                                                                                                                                                                                                                                                                                                                                      |

| Questions                                                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                            |
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| <p>354. Which imaging modality places dots of dissimilar gray scale on the display?</p> <p>A. A-mode                      C. B-mode<br/>B. I-mode                      D. M-mode</p>                                                                                                                                                             | <p><b>C.</b> Brightness mode, or B-mode, displays reflected echoes as spots of varying brightness. The depth of the dot is based on the time of flight. Stronger reflections create brighter dots. Weaker reflections create darker dots.</p>                                                      |
| <p>355. The mode that produces lines related to the changing position of reflectors in the body with respect to time is called ____.</p> <p>A. A-mode                      C. B-mode<br/>B. M-mode                      D. a la mode</p>                                                                                                         | <p><b>B.</b> The imaging mode that displays the position of reflectors throughout time is M-mode, or motion mode. M-mode is the only display that provides reflector position throughout time.</p>                                                                                                 |
| <p>356. To which of the following do the x-axis of a B-mode, the y-axis of an M-mode and the x-axis of an A-mode all relate?</p> <p>A. depth of view              C. echo amplitude<br/>B. go time                      D. time of flight</p>                                                                                                    | <p><b>D.</b> All three of these measurements report the reflector depth. Reflector depth is determined by a pulse's time of flight.</p>                                                                                                                                                            |
| <p>For the following 3 statements, indicate which of the transducer types are appropriate answers. (More than one answer may be correct.)</p> <p>A. linear switched array transducer<br/>B. linear phased array transducer<br/>C. mechanical transducer<br/>D. annular phased array transducer<br/>E. convex or curvilinear array transducer</p> |                                                                                                                                                                                                                                                                                                    |
| <p>357. With these transducers, the ultrasound beam is steered by a motor, a rotating reflecting mirror, or a similar device.</p>                                                                                                                                                                                                                | <p><b>C and D.</b><br/>In mechanical and annular phased array transducers, an ultrasound beam is steered using mechanical devices such as motors or mirrors.</p>                                                                                                                                   |
| <p>358. These transducers focus the ultrasound beam electronically.</p>                                                                                                                                                                                                                                                                          | <p><b>A, B, D, and E.</b><br/>Electronic focusing techniques are used in linear phased array and annular phased array transducers. A focused acoustic beam produces images with greater detail. Some linear and convex array transducers focus the beam electronically, whereas others do not.</p> |



| Questions                                                                                                                                               | Answers                                                                                                                                                                                                                                                                                                                                                                         |
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| 359. With these transducers, the ultrasound beam is focused with an acoustic lens, a mirror, or by milling the piezoelectric crystal in a curved shape. | <p><b>A, C, and E.</b></p> <p>Acoustic beams can be focused with techniques similar to those that focus light waves, including using an acoustic lens, a focusing mirror, or a curved piezoelectric crystal. Mechanical transducers, and some linear and curvilinear array transducers, use these techniques to focus acoustic beams.</p>                                       |
| With regard to mechanical transducers, are the next 4 statements true or false?                                                                         |                                                                                                                                                                                                                                                                                                                                                                                 |
| 360. The ultrasound beam is directed in many different directions to create an imaging plane.                                                           | <p><b>True.</b> With a mechanical transducer, the active element is aimed in several directions so that the pulses create a two-dimensional picture. Without this beam steering, the pulses would travel in the same direction and display only a single B-mode line.</p>                                                                                                       |
| 361. The ultrasound beam is not focused electronically.                                                                                                 | <p><b>True.</b> With mechanical transducers, focusing is not achieved electronically. The beam is focused with an acoustic lens (external) or by a curved PZT crystal (internal).</p>                                                                                                                                                                                           |
| 362. There is communication between the pulser of the ultrasound system and the piezoelectric crystal of the transducer.                                | <p><b>True.</b> The transducer's PZT <i>must</i> be directly connected to the pulser electronics of the ultrasound system. A wire provides a route for the electrical signal to travel from the pulser to the PZT. In addition, the crystal sends data back to the system regarding the reception of reflected echoes. This data goes to the receiver and creates an image.</p> |
| 363. Foci exist at multiple depths as an ultrasound beam propagates through the body.                                                                   | <p><b>False.</b> A standard mechanical transducer cannot focus at multiple depths or provide for variable or user-selectable focal depths. Mechanical transducers support only a single, unalterable focal depth.</p>                                                                                                                                                           |

| Questions                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                           |
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| <p>364. Which two of the following terms are associated with phased array transducers?</p> <ul style="list-style-type: none"> <li>A. lens</li> <li>B. multi-focus</li> <li>C. mirror</li> <li>D. adjustable</li> <li>E. external</li> </ul>                                                           | <p><b>B and D.</b> Phased array is always associated with adjustable or multi-focusing.</p>                                                                                                                                                                                                                       |
| <p>365. The minimum number of active elements in a mechanical transducer is:</p> <ul style="list-style-type: none"> <li>A. 0</li> <li>B. 1</li> <li>C. 2</li> <li>D. none of the above</li> </ul>                                                                                                     | <p><b>B.</b> A mechanical transducer may be constructed with a minimum of a single piezoelectric crystal. An imaging plane is created by mechanically steering the single crystal with a motor.</p>                                                                                                               |
| <p>366. Which best describes the elements in a linear phased array transducer?</p> <ul style="list-style-type: none"> <li>A. rectangular, 1/4 wavelength thick</li> <li>B. rectangular, 1/2 to 1/4 wavelength wide</li> <li>C. circular</li> <li>D. squares, 1/2 wavelength thick</li> </ul>          | <p><b>B.</b> Each element of a linear phased array is rectangular. There are approximately 100 to 200 elements, each having a width of 1/4 to 1/2 wavelength.</p>                                                                                                                                                 |
| <p>367. True or False? All phased array transducer systems direct ultrasound pulses in many directions to create a two-dimensional image.</p>                                                                                                                                                         | <p><b>True.</b> To create a two-dimensional image, the sound beams of annular, linear, and curvilinear phased array transducers must be steered through a path. The linear and curvilinear phased array systems steer the beam electronically, whereas the annular phased array steers the beam mechanically.</p> |
| <p>368. How are the piezoelectric crystals of a linear phased array transducer fired?</p> <ul style="list-style-type: none"> <li>A. in a single specific pattern</li> <li>B. in order, from top to bottom</li> <li>C. at exactly the same time</li> <li>D. at almost exactly the same time</li> </ul> | <p><b>D.</b> To steer and focus the ultrasound beam that a linear phased array transducer produces, the PZT crystals are excited by electronic pulses at almost the same time. Only billionths of seconds separate the electronic pulses that strike the PZT crystals in the transducer.</p>                      |

| Questions                                                                                                                                                                                                                                                                                                                                                                                     | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
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| <p>369. The pattern of electrical signals exciting the piezoelectric crystals of a linear phased array transducer ____.</p> <ul style="list-style-type: none"> <li>A. typically changes from one acoustic pulse to the next</li> <li>B. changes every fourth or fifth acoustic pulse</li> <li>C. changes only when the maximum imaging depth changes</li> <li>D. none of the above</li> </ul> | <p><b>A.</b> The pattern of the electrical signals that excite the PZT crystals of a linear phased array transducer changes from one pulse to the next. The electrical patterns determine the direction and focusing of each acoustic pulse. Each sound wave is directed in a slightly different direction to create a two-dimensional imaging plane. Thus, the electrical signals vary for each acoustic pulse. The electronics that creates the varying patterns is called the beam former.</p> |
| <p>370. True or False? The "curved pattern" of delays in the electrical spikes used in a linear phase array transducer focuses the beam during transmission.</p>                                                                                                                                                                                                                              | <p><b>True.</b> Focusing using time delays of the electrical spikes is a form of transmit focusing.</p>                                                                                                                                                                                                                                                                                                                                                                                           |
| <p>371. True or False? The "curved pattern" of delays in the electrical spikes used in a linear phase array transducer focuses the beam during reception.</p>                                                                                                                                                                                                                                 | <p><b>False.</b> Focusing using time delays of the electrical spikes is a form of transmit, not receive, focusing.</p>                                                                                                                                                                                                                                                                                                                                                                            |
| <p>372. True or False? Both linear and phased array technologies have the ability to variably focus an ultrasound beam to different depths.</p>                                                                                                                                                                                                                                               | <p><b>True.</b> With the phased delivery of electrical pulses to the crystals, the ultrasound beam may be focused at a variety of different depths.</p>                                                                                                                                                                                                                                                                                                                                           |
| <p>373. Which of the following forms of focusing is different from the others?</p> <ul style="list-style-type: none"> <li>A. lens</li> <li>B. mirror</li> <li>C. phased</li> <li>D. dynamic receive</li> </ul>                                                                                                                                                                                | <p><b>D.</b> Dynamic receive focusing is accomplished during reception of reflected sound. The other three techniques are forms of focusing during transmission.</p>                                                                                                                                                                                                                                                                                                                              |
| <p>374. All of the following describe dynamic receive focusing except:</p> <ul style="list-style-type: none"> <li>A. delay pattern changes continuously throughout reception</li> <li>B. may be used by single crystal transducers</li> <li>C. focusing occurs at many depths</li> <li>D. automatically performed by system</li> </ul>                                                        | <p><b>B.</b> Dynamic receive focusing is used only with systems using array transducers. Focusing is accomplished automatically during reception and is outside the control of the sonographer.</p>                                                                                                                                                                                                                                                                                               |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                                                                                     |
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| <p>375. What is the shape of the elements in an annular phased array transducer?</p> <ul style="list-style-type: none"> <li>A. rectangles</li> <li>B. squares</li> <li>C. wedges</li> <li>D. circles</li> </ul>                                                                                                                                                                                                                                                                                       | <p><b>D.</b> Annular array transducers have piezoelectric crystals that are donut or ring shaped. They are arranged as a collection of concentric rings.</p>                                                                                                                                                                                                                                |
| <p>376. True or False? Annular phased array transducers focus sound beams in all planes and at all depths.</p>                                                                                                                                                                                                                                                                                                                                                                                        | <p><b>True.</b> With annular arrays, the sound beam has the appearance of a straw. It is focused in all planes and at all depths.</p>                                                                                                                                                                                                                                                       |
| <p>377. What is true of the electrical pulses that excite the active elements of an annular phased array transducer?</p> <ul style="list-style-type: none"> <li>A. they arrive at each piezoelectric crystal at exactly the same time</li> <li>B. they vary in amplitude based on the direction of the steering and focusing</li> <li>C. they excite the crystals at different times, nanoseconds apart</li> <li>D. they arrive at each PZT crystal at different times, microseconds apart</li> </ul> | <p><b>D.</b> Annular array technology fires the piezoelectric crystals in a particular sequence to produce a focused ultrasound beam. The electrical pulses that excite the ringed elements of the array arrive at slightly different times, separated by only very small fractions of a second.</p>                                                                                        |
| <p>378. How are the piezoelectric crystals excited when using an ultrasound system with a sequential linear array transducer?</p> <ul style="list-style-type: none"> <li>A. singly and in order: the first crystal, second, then the third, etc.</li> <li>B. in pairs: the first two crystals, the 3rd and 4th, the 5th and 6th, etc.</li> <li>C. in a specific order</li> <li>D. in a random sequence</li> </ul>                                                                                     | <p><b>C.</b> Sequential linear array transducers fire small groups of piezoelectric crystals in a specific succession or progression. The order of firing is determined by the manufacturer, and is chosen to produce the highest quality image. There is, however, no specific order that <b>all</b> linear arrays use. The firing pattern is best described as "in a specific order."</p> |
| <p>379. Which best describes the elements in a linear sequential array transducer?</p> <ul style="list-style-type: none"> <li>A. rectangular, 1/4 wavelength thick</li> <li>B. rectangular, 1/4 to 1/2 wavelength wide</li> <li>C. rectangular, 1 wavelength wide</li> <li>D. squares, 1 wavelength thick</li> </ul>                                                                                                                                                                                  | <p><b>C.</b> Each element of a linear sequential array is rectangular. There are many elements, each with a width of one wavelength.</p>                                                                                                                                                                                                                                                    |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                          |
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| <p>380. What image is created with a two-dimensional array transducer?</p> <ul style="list-style-type: none"> <li>A. two-dimensional static image</li> <li>B. two-dimensional real-time image</li> <li>C. three-dimensional real-time image</li> <li>D. B-mode</li> </ul>                                                                                                                                                                                                           | <p>C. A two-dimensional array transducer creates a three-dimensional image.</p>                                                                                                                                                                                                                  |
| <h2 style="text-align: center;">TWO DIMENSIONAL IMAGING</h2>                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                  |
| <p>For the following 6 statements, indicate which of the transducer types are appropriate answers. (More than one answer may be correct.)</p> <ul style="list-style-type: none"> <li>A. linear switched (also called linear sequential) array transducer</li> <li>B. linear phased array transducer</li> <li>C. mechanical transducer</li> <li>D. annular phased array transducer</li> <li>E. convex or curvilinear array transducer</li> <li>F. vector array transducer</li> </ul> |                                                                                                                                                                                                                                                                                                  |
| <p>381. These transducers steer the beam with a motor and focus the beam with an acoustic lens or a curved PZT element.</p>                                                                                                                                                                                                                                                                                                                                                         | <p>C. Only a mechanical scanner has these characteristics.</p>                                                                                                                                                                                                                                   |
| <p>382. These transducer systems typically produce an image that, throughout its entire depth, is approximately as wide as the ultrasound transducer itself.</p>                                                                                                                                                                                                                                                                                                                    | <p>A. The width of a linear sequential array transducer determines the width of the 2-D image that it creates.</p>                                                                                                                                                                               |
| <p>383. Ultrasound systems using these transducers do not actually steer the ultrasound beams to create a two-dimensional image.</p>                                                                                                                                                                                                                                                                                                                                                | <p>A and E. Linear and convex switched (or sequential arrays) do not steer sound beams. Rather, a small group of elements produce a pulse that travels straight ahead.</p>                                                                                                                       |
| <p>384. A special sector shape is produced when this transducer is used. It looks like a wedge or a slice of pie, but it doesn't originate at a point. The sector has a blunted, curved shape at the top. The arc at the top of the image may be a few centimeters wide.</p>                                                                                                                                                                                                        | <p>E. Curved array transducers create a special form sector that starts at an initial width and gets progressively larger. If the PZT crystals are arranged in an arc of 2 to 4 cm, the image will be 2 to 4 cm wide at its top. From that dimension, the image becomes progressively wider.</p> |

| Questions                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                              |
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| 385. With these transducers, a sector (wedge-shaped or "slice of pie") image is produced. At the top, the sector is very narrow and tapers to a point.                                                                             | <b>B, C, and D.</b> Transducers that steer beams from a single point usually create sector-shaped images, like spokes on a bicycle wheel that radiate from a single point.                                                                           |
| 386. With these transducers, a trapezoidal image shape is produced. The image is flat at the top and becomes progressively wider at increasing depths.                                                                             | <b>F.</b> Vector arrays create this image shape. The vector transducer is a combination of linear phased and linear switched array technologies.                                                                                                     |
| 387. When looking at images produced by these transducer systems, which one can be distinguished from all the others?<br>A. linear phased array<br>B. linear switched array<br>C. annular phased array<br>D. mechanical transducer | <b>B.</b> The linear switched arrays (or linear sequential arrays) produce an image of rectangular shape. The other three transducers generate sector-shaped images that are essentially indistinguishable from each other.                          |
| 388. What is the advantage of using a 1½ dimensional array transducer?<br>A. improved elevational resolution<br>B. improved lateral resolution<br>C. improved axial resolution<br>D. improved temporal resolution                  | <b>A.</b> A 1½ dimensional array transducer creates a thinner imaging plane. Thin imaging planes have superior elevational, or slice thickness, resolution.                                                                                          |
| 389. Which transducer possesses the best slice thickness resolution?<br>A. linear phased arrays<br>B. 2-D arrays<br>C. 1½ dimensional arrays<br>D. linear sequential arrays                                                        | <b>C.</b> The greatest advantage of 1½ dimensional arrays is that they create very thin ultrasound slices.                                                                                                                                           |
| 390. What is the use of a greater number of channels to receive echoes from ever increasing depths called?<br>A. dynamic aperture<br>B. apodization<br>C. dynamic frequency tuning<br>D. subdicing                                 | <b>A.</b> Dynamic aperture is a technique of receive focusing that uses fewer crystals to identify echoes from superficial depths and many more crystals to monitor echoes from greater depths. Dynamic aperture is also known as variable aperture. |



| Questions                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                |
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| <p>391. The excitation of array elements with dissimilar voltages is called ____ and is used to ____.</p> <p>A. dynamic aperture, reduce refraction<br/>B. subdicing, eliminate lobes<br/>C. apodization, remove flash artifact<br/>D. apodization, reduce lobe artifact</p>                                                                        | <p>D. Apodization describes the excitation of a number of PZT elements with different voltages. This acts to decrease the strength of off-axis sound beams and reduce lobe artifact.</p>                                                                                                                                                               |
| TEMPORAL RESOLUTION and REAL-TIME IMAGING                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                        |
| <p>392. Which of the following will improve a system's temporal resolution?</p> <p>A. increased sector angle<br/>B. increased line density<br/>C. increased PRF<br/>D. increased frequency</p>                                                                                                                                                      | <p>C. To improve temporal resolution, increase the number of images produced each second. If the number of pulses emitted per second is increased (choice C) then the system can increase the frame rate. Increased PRF is obtained by decreasing the maximum imaging depth. A, B, and D all decrease frame rate and decrease temporal resolution.</p> |
| <p>393. True or False? An ultrasound system with a longer pulse duration will generally have better temporal resolution.</p>                                                                                                                                                                                                                        | <p><b>False.</b> Temporal resolution of a system is unaffected by the pulse duration.</p>                                                                                                                                                                                                                                                              |
| <p>394. True or False? The length of a pulse does not directly influence the temporal resolution.</p>                                                                                                                                                                                                                                               | <p><b>True.</b> Temporal resolution is not affected by the length of the pulses produced by the system. The factors that influence the temporal resolution are maximum imaging depth, sector angle, line density, and the number of foci per scan line.</p>                                                                                            |
| <p>395. Two imaging systems produce acoustic pulses; one pulse is 0.4 <math>\mu</math>sec long and the other is 0.2 <math>\mu</math>sec long. Which is most likely to provide the best temporal resolution?</p> <p>A. 0.4 <math>\mu</math>sec system<br/>B. 0.2 <math>\mu</math>sec system<br/>C. they are the same<br/>D. cannot be determined</p> | <p>D. Temporal resolution is unrelated to pulse duration. Temporal resolution is determined by the number of frames, or images, that are produced each second. There is insufficient information to answer the question.</p>                                                                                                                           |

| Questions                                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                                                                                                                                                 |
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| <p>396. Which two factors determine temporal resolution?</p> <ul style="list-style-type: none"> <li>A. speed of sound and depth of view</li> <li>B. pixel size and sector size</li> <li>C. focal zones and sector depth</li> <li>D. propagation speed and frame rate</li> </ul>                                                        | <p><b>A.</b> Of the 4 choices, propagation speed and depth of view have the greatest effect upon frame rate and temporal resolution. Frame rate is high with shallow imaging. Frame rate is high when sound travels quickly in a medium.</p>                                                                            |
| <p>397. Which two controls determine a system's temporal resolution?</p> <ul style="list-style-type: none"> <li>A. frame rate and sector size</li> <li>B. focal zones and sector depth</li> <li>C. propagation speed and frame rate</li> <li>D. depth of view and pulses per image</li> </ul>                                          | <p><b>D.</b> Depth of view and number of pulses per image determine the frame rate (and temporal resolution) of an ultrasound system. The sonographer can alter both of these factors.</p>                                                                                                                              |
| <p>398. True or False? An ultrasound system with a shorter pulse repetition period (PRP) will have better temporal resolution than a system with a longer PRP.</p>                                                                                                                                                                     | <p><b>True.</b> An ultrasound system with a shorter PRP has the ability to produce more pulses each second. With more pulses per second, the system creates many images per second. Increased frame rate improves temporal resolution.</p>                                                                              |
| <p>399. What is the primary disadvantage of multiple focal zones along each scan line of a two-dimensional image?</p> <ul style="list-style-type: none"> <li>A. improved temporal resolution</li> <li>B. decreased temporal resolution</li> <li>C. improved lateral resolution</li> <li>D. improved longitudinal resolution</li> </ul> | <p><b>B.</b> With multiple foci along each scan line, the ultrasound system uses many pulses to create each image. This reduces the number of frames created per second. A low frame rate results in decreased temporal resolution.</p>                                                                                 |
| <p>400. What is the primary advantage of multiple focal zones along each scan line of a two-dimensional image?</p> <ul style="list-style-type: none"> <li>A. improved temporal resolution</li> <li>B. decreased temporal resolution</li> <li>C. improved lateral resolution</li> <li>D. improved longitudinal resolution</li> </ul>    | <p><b>C.</b> Multiple foci along a single scan line creates a composite beam that is extremely narrow. Narrow sound beams create images with superior lateral resolution at all depths. Single focus systems use a single sound beam to create each scan line, and lateral resolution is optimal at only one depth.</p> |



| Questions                                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
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| <p>401. Which choice will result in increased frame rate and temporal resolution?</p> <p>A. decreased propagation speed<br/>B. decreased sector size<br/>C. decreased lateral resolution<br/>D. decreased pulse repetition frequency</p>                                                                  | <p><b>B.</b> A narrower sector diminishes the number of pulses required to produce each image. Frame rate and temporal resolution improves when fewer pulses make each image.</p>                                                                                                                                                                                                                                                                                                                                                                                                         |
| <p>402. True or False? With sector scanning, images with greater detail (spatial resolution) are created when the number of acoustic pulses per degree of sector is increased.</p>                                                                                                                        | <p><b>True.</b> Spatial resolution is improved with more pulses per degree of sector. When the line density is low, gaps may exist between adjacent pulses. Reflectors within the gaps will not accurately appear on the image.</p>                                                                                                                                                                                                                                                                                                                                                       |
| <p>403. An ultrasound system with a 4.0 MHz transducer is used to image structures as deep as 15 cm. Twenty images are produced each second, each requiring 100 acoustic pulses. What is the PRF of the system?</p> <p>A. 1,500 Hz<br/>B. 300 Hz<br/>C. 2,000 Hz<br/>D. 4 MHz</p>                         | <p><b>C.</b> Pulse repetition frequency is defined as the number of pulses produced by an ultrasound system in one second. In this example, 100 pulses are required to construct a single image, and 20 images are displayed each second. Thus, a total of 2,000 pulses are used each second to meet the imaging requirements of this system; this is the PRF. In this question, frequency and imaging depth are unimportant.</p>                                                                                                                                                         |
| <p>404. Which of the following sector imaging systems will have the best image detail if all other parameters are identical?</p> <p>A. a 90° sector with 100 pulses/image<br/>B. an 80° sector with 40 pulses/image<br/>C. a 70° sector with 84 pulses/image<br/>D. a 60° sector with 60 pulses/image</p> | <p><b>C.</b> The best image detail is provided by the system with the highest line density. Line density is defined as the number of acoustic lines per degree of sector angle. The more lines per sector degree, the closer together the scan lines are, and the greater the anatomic detail displayed.</p> <p>Choice C has 1.2 acoustic pulses per degree (84/70), choice A has a line density of 1.11 (100/90) lines/degree, choice B has 0.5 (40/80) lines/degree, and choice D has 1 (60/60) line/degree. Choice C has the highest line density and the best spatial resolution.</p> |



| Questions                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                                                                                                                                                      |
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| <p>405. Of the following, which imaging modality has the poorest temporal resolution?</p> <ul style="list-style-type: none"> <li>A. two-dimensional, real-time</li> <li>B. A-mode</li> <li>C. color flow imaging</li> <li>D. M-mode</li> </ul>                                                                                  | <p>C. Of the choices, color flow imaging has the lowest temporal resolution. Many pulses are required to create a single color flow image. The large number of pulses required for each image results in a low frame rate and poor temporal resolution.</p>                                                                                                  |
| <p>406. Which ultrasound imaging modality has the best temporal resolution?</p> <ul style="list-style-type: none"> <li>A. B-scanning</li> <li>B. duplex imaging</li> <li>C. color flow imaging</li> <li>D. M-mode</li> </ul>                                                                                                    | <p>D. Temporal resolution is the ability to accurately record the position of moving reflectors. With M-mode, the ultrasound pulse tracks reflector position in only a single dimension (depth only) and delivers extremely fine temporal resolution. The remaining choices all operate in two dimensions and do so by compromising temporal resolution.</p> |
| <p>407. All of the following reduce temporal resolution by increasing the number of pulses per image <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. increasing the number of foci</li> <li>B. increasing line density</li> <li>C. increasing field of view</li> <li>D. increasing depth of view</li> </ul>        | <p>D. Increasing the depth of view does not alter the number of pulses per image. Increasing depth of view decreases temporal resolution by changing the pulse repetition period while leaving the number of pulses in each image unchanged.</p>                                                                                                             |
| <p>408. A sonographer reduced the sector size from 90 degrees to 30 degrees. Frame rate, however, did not change. What else happened?</p> <ul style="list-style-type: none"> <li>A. imaging depth decreased</li> <li>B. pulse duration increased</li> <li>C. multi-focus was turned on</li> <li>D. PRF was increased</li> </ul> | <p>C. The question states that sector size was decreased. By itself, this would increase frame rate.</p> <p>Thus, the correct answer to this question is something that would decrease frame rate. The only selection that decreases frame rate is the use of multiple focal points, choice C.</p>                                                           |
| <b>INSTRUMENTATION</b>                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                              |
| <p>409. Which of the following is not considered a component of an ultrasound system?</p> <ul style="list-style-type: none"> <li>A. master synchronizer</li> <li>B. pulser</li> <li>C. receiver</li> <li>D. image intensifier</li> </ul>                                                                                        | <p>D. An ultrasound system is considered to have six components: transducer, pulser, receiver, image processor, display, and master synchronizer. An image intensifier is part of an x-ray imaging system.</p>                                                                                                                                               |

| Questions                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                       |
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| <p>410. True or False? The pulser of a mechanical transducer is typically more complex than the pulser of a phased array transducer.</p>                                                                       | <p><b>False.</b> A single electrical signal excites the PZT crystal of a mechanical transducer. With phased array technology, many crystals are excited nearly simultaneously to produce an acoustic pulse. Phased array systems use this technique to steer and focus sound beams. Thus, phased array systems have more complex pulsers.</p> |
| <p>411. What is a typical pulser output voltage that excites a piezoelectric crystal?</p> <p>A. 0.1 volts<br/>B. 500 millivolts<br/>C. 40 volts<br/>D. 10 microvolts</p>                                       | <p><b>C.</b> The signal typically produced by the pulser of an ultrasound system, used to excite the transducers's piezoelectric crystals, may be in the range of tens of volts.</p>                                                                                                                                                          |
| <p>412. What is the typical voltage of the signal that is the input to the receiver of an ultrasound system?</p> <p>A. 0.1 volts<br/>B. 500 mvolts<br/>C. 250 volts<br/>D. 10 <math>\mu</math>volts</p>        | <p><b>D.</b> The signal produced by the transducer upon reception and sent to the receiver of the ultrasound system is extremely small and is in the micro- to millivolt range.</p>                                                                                                                                                           |
| <p>413. The output of an ultrasound pulser determines the ____ of the acoustic pulse.</p> <p>A. imaging depth<br/>B. intensity<br/>C. duration<br/>D. pulse repetition period</p>                              | <p><b>B.</b> The output of the pulser determines the strength or the intensity of the sound beam produced by the transducer. When greater electrical voltages from the pulser strike the PZT crystal of the transducer, pulses with greater intensity are created.</p>                                                                        |
| <p>414. Which one of the following does not belong in the group below?</p> <p>A. receiver gain<br/>B. energy output<br/>C. pulser power<br/>D. acoustic power<br/>E. transmitter output<br/>F. output gain</p> | <p><b>A.</b> All of the terms listed as answers, except for choice A, refer to the strength of the signal produced by the transducer and transmitted into the body. Receiver gain is not synonymous with the other five choices.</p>                                                                                                          |

| Questions                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                             |
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| 415. True or False? The sonographer can alter the pulser power.                                                                                                                                           | <b>True.</b> The output voltage of the pulser and the strength of the acoustic pulse produced by the transducer are in the sonographer's control. The output power has different names depending on the manufacturer, but the sonographer can always alter its level.               |
| 416. Which of the following actions will improve the signal-to-noise ratio?<br>A. increase dynamic range<br>B. increase receiver gain<br>C. increase output power<br>D. increase time-gain compensation   | <b>C.</b> Increasing output power will improve the signal-to-noise ratio. When the pulse's strength is increased, reflections arriving at the transducer are stronger as well. Strong reflections are less susceptible to the image degrading effects of noise.                     |
| 417. Which of these functions are performed by the receiver of an ultrasound system? (More than one answer may be correct.)<br>A. amplification<br>B. threshold<br>C. compensation<br>D. demodulation     | <b>A, B, C, and D.</b><br>All of the functions listed above are performed by the ultrasound system's receiver.                                                                                                                                                                      |
| 418. Which of the following tasks is not performed by the receiver of an ultrasound system? (More than one answer may be correct.)<br>A. rectification<br>B. smoothing<br>C. compression<br>D. degaussing | <b>D.</b> Degaussing is the only task listed above that is not performed by the system's receiver.                                                                                                                                                                                  |
| 419. True or False? The sonographer can adjust the receiver gain.                                                                                                                                         | <b>True.</b> The sonographer is in direct control of the receiver gain. The sonographer determines the degree to which the signal returning from the transducer is amplified. It is a primary control on the ultrasound system that helps determine the ultimate quality of images. |
| 420. True or False? The signal-to-noise ratio remains unchanged when a sonographer adjusts receiver gain.                                                                                                 | <b>True.</b> Adjustments to receiver gain alter both the meaningful signal and the destructive noise to the same extent. Therefore, the signal-to-noise ratio is unaltered.                                                                                                         |



| Questions                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                                                                      |
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| <p>421. True or False? The sonographer can make an image of uniform brightness by adjusting both output power and receiver gain.</p>                                                                                             | <p><b>False.</b> Neither output power nor receiver gain can create images of uniform brightness because they do not correct for attenuation. The function that corrects for attenuation is called time-gain compensation, or TGC.</p>                                                                                                                                                        |
| <p>422. Which of the following is a typical value for the amplification of a signal by the receiver?</p> <p>A. 50 to 100 watts<br/>B. -50 to -100 dB<br/>C. 50 to 100 dB<br/>D. 5 to 25 W/cm<sup>2</sup></p>                     | <p><b>C.</b> The amplification of the weak electrical signals that first reach the receiver range from 50 to 100 decibels. This prepares the signals for further processing.</p>                                                                                                                                                                                                             |
| <p>423. What is the process of adjusting for path length related attenuation called?</p> <p>A. compression<br/>B. compensation<br/>C. time-gain compensation<br/>D. reconfirmation</p>                                           | <p><b>B.</b> Ultrasound experiences attenuation as it travels in soft tissue. The deeper that sound travels, the weaker the reflected pulse is. Compensation is the process of adjusting for path length attenuation.</p>                                                                                                                                                                    |
| <p>424. Which receiver function creates an image of comparable brightness from top to bottom?</p> <p>A. receiver gain<br/>B. output power<br/>C. swept-gain compensation</p>                                                     | <p><b>C.</b> Compensation establishes images of uniform brightness from top to bottom. Compensation adjusts for the attenuation of sound with increasing path length.</p>                                                                                                                                                                                                                    |
| <p>425. Which transducer system is most likely to have the longest delay in its TGC curve?</p> <p>A. a 5 MHz linear array<br/>B. a 2.5 MHz annular array<br/>C. a 7.5 MHz mechanical transducer<br/>D. a 5 MHz annular array</p> | <p><b>B.</b> The 2.5 MHz transducer will have a longer delay in the TGC curve. Low frequency ultrasound waves attenuate to a lesser extent than high frequency waves. Since choice B has the lowest frequency, it will have the least amount of attenuation and will require less compensation in the near zone. The type of transducer (e.g., annular, linear) does not affect the TGC.</p> |

| Questions                                                                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                   |
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| <p>426. All of the following are used to describe compensation <i>except</i>.</p> <ul style="list-style-type: none"> <li>A. swept gain</li> <li>B. depth gain</li> <li>C. time gain</li> <li>D. amplitude gain</li> </ul>                                                                                                                                                      | <p><b>D.</b> The terms swept gain, depth gain, and time gain are used interchangeably when describing compensation. The term amplitude gain is not synonymous with the other three terms.</p>                             |
| <p>427. Which term best describes the region of minimum amplification on a standard TGC curve?</p> <ul style="list-style-type: none"> <li>A. far field</li> <li>B. focus only</li> <li>C. area close to the transducer</li> <li>D. focal zone</li> </ul>                                                                                                                       | <p><b>C.</b> The region of minimum amplification on a TGC curve, often called the "delay," is always associated with the area close to the transducer.</p>                                                                |
| <p>428. What does the far gain of a depth gain compensation curve represent?</p> <ul style="list-style-type: none"> <li>A. the median amplification related to compensation</li> <li>B. the maximum amplification related to compensation</li> <li>C. the minimum amplification related to compensation</li> <li>D. the maximum attenuation related to compensation</li> </ul> | <p><b>B.</b> The far gain setting of a TGC curve represents the maximum amplification that a reflected wave undergoes during the compensation process.</p>                                                                |
| <p>429. At which imaging depth is the slope of the TGC curve most effective?</p> <ul style="list-style-type: none"> <li>A. the region very close to the transducer</li> <li>B. the far zone</li> <li>C. the focal zone</li> </ul>                                                                                                                                              | <p><b>C.</b> TGC is most effective in improving image quality in the focal zone. Compensating for attenuation in the focal zone allows the ultrasound system to produce high-quality scans with detailed information.</p> |
| <p>430. True or False? The lower the frequency of the ultrasound beam, the shallower is the delay of the TGC curve.</p>                                                                                                                                                                                                                                                        | <p><b>False.</b> With lower sound frequencies, the delay of the TGC curve is deeper. There is less attenuation with low frequency sound, and this allows for a deeper TGC delay.</p>                                      |
| <p>431. True or False? Typically, the sonographer can adjust the compression function of a receiver.</p>                                                                                                                                                                                                                                                                       | <p><b>True.</b> Part of the compression function involves the assignment of gray scale levels on the display. This is adjusted by the operator.</p>                                                                       |

| Questions                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                       |
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| <p>432. The process of demodulation incorporates which of the following tasks? (More than one answer may be correct.)</p> <ul style="list-style-type: none"> <li>A. smoothing</li> <li>B. amplification</li> <li>C. rectification</li> <li>D. decompression</li> </ul>                                              | <p><b>A and C.</b></p> <p>Demodulation is a two-step process. These steps are rectification and smoothing.</p>                                                                                                                |
| <p>433. Which of the following best describes the demodulation process?</p> <ul style="list-style-type: none"> <li>A. changing the gray scale of an image</li> <li>B. changing the frequency of a signal</li> <li>C. changing the form of a sound pulse</li> <li>D. changing an electrical signal's form</li> </ul> | <p><b>D.</b> Demodulation alters the form or shape of electrical signals within the receiver.</p>                                                                                                                             |
| <p>434. True or False? The primary purpose of demodulation is the preparation of the electrical signal for display on a television monitor.</p>                                                                                                                                                                     | <p><b>True.</b> The primary purpose for demodulating a signal within an ultrasound system is to prepare it for ultimate display on a television monitor.</p>                                                                  |
| <p>435. True or False? Typically, the sonographer can control the demodulation process performed by a receiver.</p>                                                                                                                                                                                                 | <p><b>False.</b> With the majority of ultrasound systems, the process of demodulation is not under the sonographer's control. The parameters of demodulation are set within the ultrasound system and cannot be adjusted.</p> |
| <p>436. The process of eliminating low amplitude signals from further processing is called all of the following <i>except</i> ____.</p> <ul style="list-style-type: none"> <li>A. reject</li> <li>B. subordination</li> <li>C. threshold</li> <li>D. suppression</li> </ul>                                         | <p><b>B.</b> The process of removing low-level signals from further processing or display by an ultrasound system is called reject, threshold, or suppression. The term subordination does not describe this process.</p>     |
| <p>437. True or False? Typically, the sonographer can adjust the threshold level.</p>                                                                                                                                                                                                                               | <p><b>True.</b> Under normal circumstances, the operator adjusts the reject (suppression or threshold) level that is performed during signal processing.</p>                                                                  |



| Questions                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                                                                                                      |
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| <b>DISPLAYS</b>                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                              |
| <p>438. A video display that is limited to black and white only, with no shades of gray, is called ____.</p> <p>A. binary<br/>B. bistable<br/>C. monochrome<br/>D. inchworm</p>                                                                                                                      | <p><b>B.</b> A video display with the ability to show black and white only, without any intermediate shades of gray, is called bistable.</p>                                                                                                                                                                                                                                 |
| <p>439. What is the approximate number of frames that must be presented each second for the human eye to perceive the display without flickering?</p> <p>A. 2<br/>B. 30<br/>C. 100<br/>D. 500</p>                                                                                                    | <p><b>B.</b> The frame rate required to perceive smooth, flicker-free motion is in the range of 30 frames/sec. When the frame rate is significantly below this value, the viewer experiences flicker. Flicker increases fatigue and discomfort and diminishes the perceptive ability of the observer.</p>                                                                    |
| <p>440. What was the original purpose for the ultrasound system's analog scan converter?</p> <p>A. to increase the dynamic range of ultrasound systems<br/>B. to make real-time imaging possible<br/>C. to increase the sensitivity of ultrasound systems<br/>D. to allow for gray scale imaging</p> | <p><b>D.</b> The introduction of scan converter technology in ultrasound allowed for the presentation of gray scale images. That is, the images were not limited to black and white (bistable), but had various shades of gray within them. Additionally, the scan converter changed the format of the system's data from penetrations to a format suitable for display.</p> |
| <p>441. Which of the following is best described as an analog number?</p> <p>A. the weight of a person<br/>B. the number of people in a room<br/>C. the number of stars in the sky<br/>D. the number of tires on a car</p>                                                                           | <p><b>A.</b> The weight of a person can be considered an analog number because it is continuous and can achieve an unlimited number of values. On the other hand, the number of people in a room or the number of tires on an automobile can be represented only by discrete, whole, or integer values.</p>                                                                  |
| <p>442. True or False? A digital representation of a number can achieve only specific fixed values.</p>                                                                                                                                                                                              | <p><b>True.</b> A digital representation of a number is limited to discrete values and cannot take on unlimited values. Because of this, digital scan converters can store only a fixed number of gray shades.</p>                                                                                                                                                           |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                  | Answers                                                                                                                                                                                                                                                                                                  |
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| 443. True or False? Digital scan converters do not use computer technology to process electronic data into images.                                                                                                                                                                                                                                                                                         | <b>False.</b> Digital scan converters use computer technology to process data.                                                                                                                                                                                                                           |
| 444. Two digital scan converters are undergoing evaluation. Both produce images of the same size. System A has 1,000,000 pixels, with 10 bits assigned to each. System B has 250,000 pixels, with 12 bits assigned to each. Which system is more likely to have the capability to display very small details in an image?<br>A. System A<br>B. System B<br>C. both are the same<br>D. cannot be determined | <b>A.</b> The scan converter with the greatest number of pixels assigned to an image of fixed size will provide the viewer with the greatest spatial detail. In this case, system A has a higher pixel density, and therefore has the ability to display greater detail.                                 |
| 445. What happens to a digital image when the pixel density increases?<br>A. spatial detail improves<br>B. temporal resolution increases<br>C. the field of view expands<br>D. there are more shades of gray                                                                                                                                                                                               | <b>A.</b> The pixel density, the number of pixels per inch, determines the detail that a digital picture can illustrate. With greater pixel density, spatial detail improves.<br><br>Alternatively, the image has less detail with fewer pixels per inch.                                                |
| 446. Two digital scan converters are undergoing evaluation. System A has 1,000,000 pixels and the picture size is 100 square inches. System B has an image size of 10 square inches composed of 250,000 pixels. Which image is more likely to display very small details?<br>A. System A<br>B. System B<br>C. both are the same<br>D. cannot be determined                                                 | <b>B.</b> System B has a greater ability to display small detail in an image in comparison to system A. System B has 25,000 pixels per square inch, whereas system A only has 10,000 pixels per square inch. System B has a greater pixel density, and this determines the degree of spatial resolution. |
| 447. What is the smallest part of a digital picture called?<br>A. bit<br>B. byte<br>C. pixel<br>D. fractel                                                                                                                                                                                                                                                                                                 | <b>C.</b> The basic element of a digital representation of an image is the pixel. The term is derived from the words "picture element".                                                                                                                                                                  |



| Questions                                                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                       |
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| 448. True or False? The greater the number of bits assigned to each pixel of a digital image, the greater the number of shades of gray the image has.                                                                                                                                                                                                          | <b>True.</b> The number of gray shades in an image increases when the number of bits assigned to each pixel increases.                                                                                                                                        |
| 449. What is the smallest amount of digital storage called?<br>A. bit<br>B. byte<br>C. pixel<br>D. fractel                                                                                                                                                                                                                                                     | <b>A.</b> The bit is the smallest amount of digital storage or computer memory. The term bit is derived from the words "binary digit." A combination of eight bits makes a byte.<br><br>Computer memory is called random access memory, or RAM.               |
| 450. Which of these is a binary number?<br>A. 12211221<br>B. 10000000<br>C. 98765432<br>D. 01010102                                                                                                                                                                                                                                                            | <b>B.</b> A binary number is a string of zeroes and ones only. Binary numbers are based on two choices. Digital numbers are based on ten choices.                                                                                                             |
| 451. Two digital scan converters are undergoing evaluation. System A has 1,000,000 pixels, with 4 bits assigned to each. System B has 250,000 pixels, with 12 bits assigned to each. Which system is more likely to display images with very subtle differences in grayscale?<br>A. System A<br>B. System B<br>C. both are the same<br>D. cannot be determined | <b>B.</b> Gray scale levels are determined by the number of bits assigned to each pixel in an image. Since system B has 12 bits assigned to each pixel and system A has only 4, system B will display more gray shades and, thus, display subtle differences. |
| 452. A byte is composed of ____ bits. A word is composed of ____ bytes.<br>A. 2, 2<br>B. 8, 2<br>C. 16, 16<br>D. 8, 16                                                                                                                                                                                                                                         | <b>B.</b> A string of eight bits of computer memory is a byte. Two bytes of computer memory make a word.<br><br>Since a byte is 8 bits, a word is 16 bits.                                                                                                    |
| 453. True or False? The greater the number of bits assigned to each pixel of a digital image, the greater the spatial resolution of the image is.                                                                                                                                                                                                              | <b>False.</b> The number of bits assigned to each pixel of a digital image does not directly affect the spatial resolution of the image.                                                                                                                      |



| Questions                                                                                                                                                                                                                          | Answers                                                                                                                                                                                                                                                                                                         |
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| <p>454. What happens to an image when the number of bits allocated to each pixel increases?</p> <p>A. spatial detail improves<br/>B. frame rate increases<br/>C. field of view expands<br/>D. more shades of gray</p>              | <p>D. In a digital representation of an image, as the number of bits assigned to each pixel increases, the number of different shades of gray in the image increases.</p>                                                                                                                                       |
| <p>455. What is the maximum number of shades of gray that are represented with 4 bits?</p> <p>A. 4<br/>B. 8<br/>C. 12<br/>D. 16</p> <p><i>Handwritten: 2 → 4 → 8 → 16, 2 · 2 · 2 · 2</i></p>                                       | <p>D. A maximum of 16 shades of gray can be represented with 4 bits. To calculate this, multiply 2 by itself the same number of times that there are bits. In this example, multiply 2 by itself a total of 4 times (there are 4 bits): <math>2 \times 2 \times 2 \times 2 = 16</math> shades.</p>              |
| <p>456. With 6 bits, what is the largest number of different gray shades that can be stored?</p> <p>A. 8<br/>B. 16<br/>C. 64<br/>D. 256</p> <p><i>Handwritten: 2 → 4 → 8 → 16 → 32 → 64, 2 · 2 · 2 · 2 · 2 · 2</i></p>             | <p>C. A maximum number of 64 shades can be stored with the use of 6 bits. We multiply 2 by itself a total of 6 times to calculate the answer to this question:<br/><math>2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64</math> shades.</p>                                                                 |
| <p>457. How many bits are required to display 10 different shades of gray? 14 shades? 15 shades?</p> <p>A. 4 bits, 5 bits, 6 bits<br/>B. 10 bits, 14 bits, 15 bits<br/>C. 4 bits, 4 bits, 2 bits<br/>D. 4 bits, 4 bits, 4 bits</p> | <p>D. Four bits of memory are required to display 10, 14, or 15 shades of gray. Three bits can display a maximum of 8 gray shades (<math>2 \times 2 \times 2 = 8</math>). Adding a single bit to the collection increases the number of gray shades to 16 (<math>2 \times 2 \times 2 \times 2 = 16</math>).</p> |
| <p>458. What is the number of binary digits required to store 29 levels of gray?</p> <p>A. 4<br/>B. 5<br/>C. 6<br/>D. 29</p>                                                                                                       | <p>B. A minimum of 5 bits are required to display 29 shades of gray. Actually, 5 bits can display a maximum of 32 shades of gray. Because only 16 shades of gray can be represented by 4 bits, a fifth bit must be added to achieve adequate memory to display more than 16 shades.</p>                         |

| Questions                                                                                                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                                                                                                                                  |
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| 459. True or False? For digital image information to be displayed on a conventional television screen, the data must be processed by a digital-to-analog converter.                                                                                                                                                                                                  | <b>True.</b> The representation of an image in digital format is not suitable for display on a standard television because a TV is an analog device. After all the signal processing is completed, the image data is passed through a digital-to-analog converter. It is then suitable for TV display.                                                   |
| 460. True or False? Preprocessing of image data occurs after the data has been stored in the scan converter.                                                                                                                                                                                                                                                         | <b>False.</b> Preprocessing of image data is achieved before image storage in the scan converter. TGC and write magnification are examples of preprocessing.                                                                                                                                                                                             |
| 461. True or False? Postprocessing of image data occurs after the data has been stored in the scan converter.                                                                                                                                                                                                                                                        | <b>True.</b> All processing that occurs after the image is stored in the scan converter is called postprocessing. Examples of postprocessing are read magnification and the various forms of gray scale assignment. Any manipulation of a frozen image is postprocessing.                                                                                |
| 462. All of the following are true of read zoom except:<br>A. preprocessing function of a receiver<br>B. same number of pixels are in the original ROI and the zoomed image<br>C. on the screen, the pixels in the zoomed image are larger than those in the ROI<br>D. the same number of ultrasound pulses are used to create the original ROI and the zoomed image | <b>A.</b> Read zoom is a postprocessing function of the receiver. The data originally in the region of interest (ROI), before zoom, remains intact. New information is not acquired.                                                                                                                                                                     |
| 463. All of the following are true of write zoom except:<br>A. preprocessing function of the receiver<br>B. the same number of pixels are in the original ROI and the zoomed image<br>C. the pixel size in the zoomed image and the ROI are the same<br>D. in comparison to the zoomed image, fewer ultrasound pulses are used to create the original ROI            | <b>B.</b> Write zoom is a preprocessing function of the receiver where new information is acquired from the region of interest (ROI). The data originally in the scan converter, before zoom, is discarded. All the pixels in the image are now concentrated into the ROI, thereby increasing the pixel density and image quality of the zoomed portion. |

| Questions                                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                                                                                 |
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| <p>464. True or False? The assignment of different shades of gray to the digital numbers stored in the scan converter acts to improve the diagnostic value of an ultrasound exam.</p>                                                                                                                            | <p><b>True.</b> By using different gray scale maps, the sonographer selects what tissue textures will be distinguished from each other on the display. This is very important when different tissues in the body produce reflections that are quite similar. By using an appropriate gray scale map, these tissues appear differently on the screen, thereby enhancing an exams's diagnostic value.</p> |
| <p>465. The relationship between the largest and the smallest signal amplitudes processed by a component of an ultrasound system is called the ____ and has units of ____.</p> <p>A. decibels, watts<br/>B. intensity, <math>\text{W}/\text{cm}^2</math><br/>C. dynamic range, dB<br/>D. proportionality, dB</p> | <p><b>C.</b> Dynamic range is defined as the ratio of the largest to the smallest signal amplitude that a device can process. The units of dynamic range are decibels, dB.</p>                                                                                                                                                                                                                          |
| <p>466. Which of these components typically has the greatest dynamic range?</p> <p>A. display<br/>B. pulser<br/>C. amplifier<br/>D. demodulator</p>                                                                                                                                                              | <p><b>C.</b> Of the four choices, the component of an ultrasound system with the greatest dynamic range is the amplifier.</p>                                                                                                                                                                                                                                                                           |
| <p>467. Which of the following components typically has the lowest dynamic range?</p> <p>A. display<br/>B. pulser<br/>C. amplifier<br/>D. demodulator</p>                                                                                                                                                        | <p><b>A.</b> Of the four choices, the component of an ultrasound system with the lowest dynamic range is the display.</p>                                                                                                                                                                                                                                                                               |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                                                  |
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| <p>468. Why is it necessary for the receiver to perform compression on the electrical signals that it processes?</p> <ul style="list-style-type: none"> <li>A. the dynamic range of the system's electronics is less than the dynamic range of the received sound reflection</li> <li>B. the display's dynamic range exceeds the transducer's dynamic range</li> <li>C. the dynamic range of the receiver is less than the dynamic range of the image processor</li> <li>D. the dynamic range of the display exceeds the dynamic range of all other components of the ultrasound system.</li> </ul> | <p><b>A.</b> The process of compression decreases the dynamic range of a signal. Ultrasound systems compress signals because the dynamic range of the reflected signals received by the transducers is far greater than the dynamic range of any of the other components of the system.</p> <p>Thus, compression matches the dynamic range of the signal to the dynamic range of the system's electrical components.</p> |
| <p>469. A signal with a 120 dB dynamic range is compressed by 40 dB. What is the dynamic range of the compressed signal?</p> <ul style="list-style-type: none"> <li>A. 40 dB</li> <li>B. 120 dB</li> <li>C. 3 dB</li> <li>D. 80 dB</li> </ul>                                                                                                                                                                                                                                                                                                                                                       | <p><b>D.</b> When a signal's dynamic range is compressed, the decibels of compression are simply subtracted.</p> <p>In this case, <math>120 - 40 = 80</math> dB.</p>                                                                                                                                                                                                                                                     |
| <p>470. A signal with a 120 dB dynamic range was previously compressed by 40 dB. What is the dynamic range of the original uncompressed signal?</p> <ul style="list-style-type: none"> <li>A. 160 dB</li> <li>B. 120 dB</li> <li>C. 3 dB</li> <li>D. 80 dB</li> </ul>                                                                                                                                                                                                                                                                                                                               | <p><b>A.</b> When a signal is already compressed, the original dynamic range is obtained by adding the decibels of compression.</p> <p>In this case, <math>120 + 40 = 160</math> dB.</p>                                                                                                                                                                                                                                 |
| <p>471. Which display is limited to a single pair of brightness or display levels?</p> <ul style="list-style-type: none"> <li>A. CRT</li> <li>B. binary</li> <li>C. bistable</li> <li>D. gray scale</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                      | <p><b>C.</b> A display that presents data in one of only two colors is bistable. Each dot on the image is either white or black, bright or dark, on or off. Bistable images are considered high contrast.</p>                                                                                                                                                                                                            |

| Questions                                                                                                                                                                                                                                                  | Answers                                                                                                                                                                                                                             |
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| <p>472. All of the following are consistent with an image containing black and white only with no shades of gray <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. bistable</li> <li>B. high contrast</li> <li>C. wide dynamic range</li> </ul> | <p>C. An image described as wide dynamic range contains many shades of gray. Wide dynamic range (also called high dynamic range) means "many choices."</p>                                                                          |
| <p>473. Which of the following terms is not associated with a wide dynamic range image?</p> <ul style="list-style-type: none"> <li>A. low contrast</li> <li>B. many shades of gray</li> <li>C. bistable</li> </ul>                                         | <p>C. A bistable image contains only black and white. An image described as wide dynamic range contains many shades of gray and may be called "low contrast."</p>                                                                   |
| HEMODYNAMICS                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                     |
| <p>474. Which of the following flow patterns is associated with cardiac contraction?</p> <ul style="list-style-type: none"> <li>A. phasic</li> <li>B. spontaneous</li> <li>C. steady</li> <li>D. pulsatile</li> <li>E. continuous</li> </ul>               | <p>D. A pulsatile flow pattern describes blood moving at a variable velocity as a result of contraction of the heart. As a result, arterial flow is often described as pulsatile.</p>                                               |
| <p>475. Which of the following terms does not belong with the others?</p> <ul style="list-style-type: none"> <li>A. phasic</li> <li>B. spontaneous</li> <li>C. pulsatile</li> <li>D. venous</li> </ul>                                                     | <p>C. Arterial flow is often described as pulsatile. Phasic or spontaneous flow patterns describe blood moving at a variable velocity as a result of the mechanics of breathing. Phasic flow is observed in venous circulation.</p> |
| <p>476. Which of the following is not associated with laminar flow?</p> <ul style="list-style-type: none"> <li>A. layered</li> <li>B. normal</li> <li>C. aligned</li> <li>D. smooth</li> <li>E. chaotic</li> </ul>                                         | <p>E. Chaotic does not describe laminar flow. Chaotic flow is associated with turbulent flow.</p>                                                                                                                                   |

| Questions                                                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                                  |
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| <p>477. Which of the following is not associated with turbulent flow?</p> <ul style="list-style-type: none"> <li>A. parabolic</li> <li>B. eddy</li> <li>C. vortex</li> <li>D. swirling</li> <li>E. spectral broadening</li> </ul>                                                    | <p>A. Parabolic flow is a bullet-shaped flow pattern associated with laminar flow. The remaining terms, B, C, D, and E are all related to turbulent flow.</p>                                                                            |
| <p>478. What is the primary reason blood moves from one location to another?</p> <ul style="list-style-type: none"> <li>A. energy gradient</li> <li>B. anemia</li> <li>C. pressure gradient</li> <li>D. systole</li> <li>E. friction</li> </ul>                                      | <p>A. Blood flows from one location to another when an energy gradient exists. Blood moves from regions of higher energy to regions of lower energy. Although choice C, pressure gradient, is attractive, it is not the best answer.</p> |
| <p>479. All of the following decrease the flow energy of a fluid <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. frictional loss</li> <li>B. viscous loss</li> <li>C. inertial loss</li> <li>D. velocity loss</li> </ul>                                                | <p>D. Three energy losses associated with flow through the circulation are frictional, viscous, and inertial loss.</p>                                                                                                                   |
| <p>480. Which of the following causes the greatest amount of inertial energy loss?</p> <ul style="list-style-type: none"> <li>A. pulsatile flow</li> <li>B. flow through a stenosis</li> <li>C. phasic flow</li> <li>D. steady flow</li> <li>E. parabolic flow</li> </ul>            | <p>B. Inertial loss is substantial when a fluid's velocity increases or decreases. Flow through a stenosis causes the greatest velocity changes, and the greatest inertial loss.</p>                                                     |
| <p>481. The arterial blood pressure of a supine individual is 120 mmHg. What is the hydrostatic pressure at the subject's ankle?</p> <ul style="list-style-type: none"> <li>A. 100 mmHg</li> <li>B. 0 mmHg</li> <li>C. 40 mmHg</li> <li>D. 120 mmHg</li> <li>E. -120 mmHg</li> </ul> | <p>B. Hydrostatic pressure is related to the difference between heart level and the site of measurement. In the supine patient, hydrostatic pressure is zero.</p>                                                                        |



| Questions                                                                                                                                                                                                                                            | Answers                                                                                                                                                                                                                          |
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| <p>482. The arterial blood pressure of a supine individual is 120 mmHg. What is the hydrostatic pressure at the subject's hips?</p> <p>A. 100 mmHg<br/>B. 0 mmHg<br/>C. 40 mmHg<br/>D. 120 mmHg<br/>E. -120 mmHg</p>                                 | <p><b>B.</b> Hydrostatic pressure is related to the difference between heart level and the site of measurement. In the supine patient, hydrostatic pressure is zero.</p>                                                         |
| <p>483. The arterial blood pressure of a standing individual is 120 mmHg. What is the hydrostatic pressure at the subject's ankle?</p> <p>A. 100 mmHg<br/>B. 0 mmHg<br/>C. 40 mmHg<br/>D. -100 mmHg<br/>E. -120 mmHg</p>                             | <p><b>A.</b> Hydrostatic pressure is related to the difference between heart level and the site of measurement. Since the ankle is substantially lower than heart level, the hydrostatic pressure is 100 mmHg.</p>               |
| <p>484. The arterial blood pressure of a standing individual is 120 mmHg at the level of the heart. What is the measured blood pressure at the subject's ankle?</p> <p>A. 100 mmHg<br/>B. 0 mmHg<br/>C. 40 mmHg<br/>D. -100 mmHg<br/>E. 220 mmHg</p> | <p><b>E.</b> Measured blood pressure is equal to the sum of actual blood pressure at heart level and hydrostatic pressure.</p> <p>In this example,<br/> <math>120 \text{ mmHg} + 100 \text{ mmHg} = 220 \text{ mmHg}.</math></p> |
| <p>485. What happens to the diaphragm when an individual breathes in?</p> <p>A. it ascends into the thorax<br/>B. it descends into the abdomen</p>                                                                                                   | <p><b>B.</b> Upon inspiration, the diaphragm moves downward into the abdomen.</p>                                                                                                                                                |
| <p>486. What happens to venous return to the heart when an individual inhales?</p> <p>A. increases<br/>B. decreases<br/>C. remains the same</p>                                                                                                      | <p><b>A.</b> Upon inspiration, venous return to the heart increases.</p>                                                                                                                                                         |

| Questions                                                                                                                               | Answers                                                                                  |
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| 487. What happens to venous flow in the legs when an individual inhales?<br>A. increases<br>B. decreases<br>C. remains the same         | B. Upon inspiration, venous flow in the legs decreases.                                  |
| 488. What happens to the diaphragm when an individual breathes out?<br>A. it ascends into the thorax<br>B. it descends into the abdomen | A. The diaphragm moves upward into the chest cavity (the thorax) when a subject exhales. |
| 489. What happens to venous return to the heart when an individual exhales?<br>A. increases<br>B. decreases<br>C. remains the same      | B. Venous return to the heart decreases when an individual exhales.                      |
| 490. What happens to venous flow in the legs when an individual exhales?<br>A. increases<br>B. decreases<br>C. remains the same         | A. Venous flow in the legs increases when an individual exhales.                         |

## DOPPLER

|                                                                                                                                                                                    |                                                                                                                                                                                                                       |
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| 491. The Doppler effect is observed as a change in ____ and has units of ____.<br>A. amplitude, watts<br>B. power, watts<br>C. frequency, per second<br>D. wavelength, millimeters | C. The Doppler effect is a change in a wave's frequency when the sound source and the receiver of the sound are in motion relative to each other. Frequency may be expressed as hertz, Hz, cycles/sec, or per second. |
| 492. In clinical imaging, which reflectors produce most relevant Doppler shifts?<br>A. blood vessels<br>B. blood plasma<br>C. platelets<br>D. red blood cells                      | D. In clinical imaging, red blood cells are the primary reflectors that produce Doppler shifts. Blood cells constantly move through the circulatory system and make up nearly 45% of the volume of the blood.         |

| Questions                                                                                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                                                                                                                              |
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| <p>493. If red blood cells are traveling toward a transducer, the frequency emitted by the transducer is ____ the frequency reflected from the red blood cells.</p> <p>A. greater than<br/>B. equal to<br/>C. less than</p>                                                                 | <p><b>C.</b> When red blood cells approach a transducer, a positive Doppler frequency shift results. The emitted frequency is less than the reflected frequency.</p>                                                                                                                                                 |
| <p>494. In standard Doppler, what is true about the reflected frequency produced by blood cells traveling away from the transducer?</p> <p>A. it is in the audible range<br/>B. it is ultrasonic<br/>C. it exceeds the transmitted frequency<br/>D. it equals the transmitted frequency</p> | <p><b>B.</b> The frequency of the sound wave reflected by red blood cells back to the transducer is ultrasonic (having a frequency greater than 20,000 hertz). Although the difference between the transmitted and reflected frequencies is audible, the reflected wave has a frequency in the ultrasonic range.</p> |
| <p>495. What is the range of Doppler shifts commonly measured in clinical exams?</p> <p>A. -10 kHz to 1 MHz<br/>B. -0.5 MHz to 0.5 MHz<br/>C. -0.02 MHz to 0.02 MHz<br/>D. none of the above</p>                                                                                            | <p><b>C.</b> Doppler shifts in clinical imaging typically range from -20,000 Hz to +20,000 Hz. Choice C has units of megahertz, but when we examine the values of -0.02 to +0.02 MHz closely, we see that this means exactly the same as -20,000 Hz to +20,000 Hz.</p>                                               |
| <p>496. When red blood cells move away from a transducer, the frequency of the wave reflected from the red cells is ____ the frequency emitted by the transducer.</p> <p>A. greater than<br/>B. less than<br/>C. equal to</p>                                                               | <p><b>B.</b> When red blood cells are moving away from a transducer, the Doppler shift is negative. The reflected frequency is less than the originally transmitted frequency from the transducer.</p>                                                                                                               |
| <p>497. What information does the Doppler shift furnish concerning the blood cells that produce it?</p> <p>A. frequency<br/>B. speed<br/>C. velocity<br/>D. density</p>                                                                                                                     | <p><b>C.</b> Doppler shifts produce information regarding velocity.</p> <p>What is the difference between speed and velocity? Speed is purely a number such as 400 m/s. Velocity is both a number and a direction, such as 200 m/s away from the transducer. Doppler shifts indicate direction and a magnitude.</p>  |



| Questions                                                                                                                                                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                                                                                            |
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| <p>498. Blood moving at a velocity of 2 m/s creates a Doppler frequency of 3,000 Hz. What will the Doppler shift be if the velocity increases to 4 m/s?</p> <p>A. 3,000 Hz<br/>B. 2 Hz<br/>C. 1,500 Hz<br/>D. 6,000 Hz</p>                                                                                                     | <p><b>D.</b> Doppler shifts are directly related to reflector velocity. Higher velocities create higher Doppler shifts. Lower velocities create lower Doppler shifts.</p> <p>When the velocity doubles, the Doppler shift doubles.</p>                                                                                                                                                             |
| <p>499. Two ultrasound transducers are used to perform Doppler exams on the same patient. The exams are identical except that the transducer frequencies are 5 and 2.5 MHz. Which exam will measure the highest velocities?</p> <p>A. the 2.5 MHz exam<br/>B. the 5 MHz exam<br/>C. neither<br/>D. cannot be determined</p>    | <p><b>C.</b> The velocities measured by Doppler exams are the same, regardless of the frequency of the transducer. Although the Doppler shifts associated with the velocities may vary with different transmitted frequencies, the measured velocities are identical.</p>                                                                                                                          |
| <p>500. Two ultrasound transducers are used to perform Doppler exams on the same patient. The exams are identical except that the transducer frequencies are 5 and 2.5 MHz. Which exam will measure the highest Doppler shift?</p> <p>A. the 2.5 MHz exam<br/>B. the 5 MHz exam<br/>C. neither<br/>D. cannot be determined</p> | <p><b>B.</b> Doppler shifts are directly related to the transmitted frequency. Higher frequency transducers produce a greater Doppler shift. Using lower frequency ultrasound will result in lower Doppler shifts.</p> <p>For a specific velocity, the Doppler shift produced will depend on the frequency of the incident sound wave, with higher frequencies yielding higher Doppler shifts.</p> |
| <p>501. When using a 4 MHz transducer, a Doppler shift of 3,000 Hz is recorded. What will the Doppler shift be when a 2 MHz transducer is used?</p> <p>A. 3,000 Hz<br/>B. 2 Hz<br/>C. 1,500 Hz<br/>D. 6,000 Hz</p>                                                                                                             | <p><b>C.</b> Doppler shifts are directly related to transducer frequency. When the frequency is halved, the Doppler shift will be halved.</p>                                                                                                                                                                                                                                                      |

| Questions                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                                         |
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| <p>502. Doppler does not always provide a valid estimate of the speed of blood cells because the shift is related to the ____ of the angle between the direction of the beam and the direction of blood flow.</p> <p>A. sine<br/>B. tangent<br/>C. cosine<br/>D. cotangent</p>                                                                                      | <p>C. Included in the Doppler equation is the <b>cosine</b> of the angle between the direction of motion and the direction of the sound beam.</p>                                                                                                                                                                                                                                                               |
| <p>503. Two otherwise identical Doppler studies are performed, except that the angle between flow and the sound beam is 0 degrees in the first study and 60 degrees in the second. The velocity measured in the first study is 2 m/s. What velocity will be measured in the second study?</p> <p>A. 2 m/s<br/>B. 4 m/s<br/>C. 1 m/s<br/>D. cannot be determined</p> | <p>C. Maximum velocities are measured at a zero degree angle. Only one-half of the true velocity is measured when the angle is 60 degrees.</p>                                                                                                                                                                                                                                                                  |
| <p>504. What is true of the Doppler shift when the sound beam is normally incident to the velocity of the red blood cells?</p> <p>A. it is at maximum<br/>B. it is half of maximum<br/>C. it is absent<br/>D. it is at minimum</p>                                                                                                                                  | <p>C. The Doppler shift is related to the angle between the directions of the blood flow and the sound wave. The cosine of this angle indicates the percentage of the true velocity that is measured by Doppler. Normal incidence indicates a 90° angle between blood flow and the sound beam. The cosine of 90° is zero. Therefore, zero percent of the velocity is measured; the Doppler shift is absent.</p> |
| <p>505. A maximum Doppler shift is obtained when the angle between the direction of blood flow and the direction of the sound beam is ____.</p> <p>A. 10 degrees<br/>B. 90 degrees<br/>C. 180 degrees<br/>D. 270 degrees</p>                                                                                                                                        | <p>C. Maximum Doppler shifts occur when red blood cells travel directly toward or directly away from a transducer. An angle of 180° between the sound source and the direction of motion exists when the cells travel directly away from the transducer.</p>                                                                                                                                                    |

| Questions                                                                                                                                                                                      | Answers                                                                                                                                                                                                                                                                                                                               |
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| 506. True or False? The appearance of negative velocities on the spectral display of a continuous wave Doppler exam always indicates that red blood cells are moving away from the transducer. | <b>True.</b> Aliasing does not occur with continuous wave Doppler. Negative velocities appear on the spectral display only when red blood cells travel away from the transducer.                                                                                                                                                      |
| With regard to CW Doppler, are the following 4 statements true or false?                                                                                                                       |                                                                                                                                                                                                                                                                                                                                       |
| 507. A minimum of two distinct piezoelectric crystals are in the transducer.                                                                                                                   | <b>True.</b> With continuous wave ultrasound, one crystal is constantly producing sound. A second crystal is required to listen for reflections.<br><br>In some pulsed ultrasound systems, the same crystal may be used for both pulsing and receiving.                                                                               |
| 508. Problems with aliasing significantly limit its clinical utility.                                                                                                                          | <b>False.</b> Aliasing is an artifact where high Doppler shifts are misidentified as flow in the opposite direction. Aliasing is produced in pulsed Doppler exams when the PRF is low compared to the Doppler frequency. Aliasing does not appear with CW Doppler.                                                                    |
| 509. Frequencies measured at the transducer are produced from many different locations along the ultrasonic beam.                                                                              | <b>True.</b> One of the characteristics of CW Doppler is that the frequencies received by the transducer can come from anywhere along the region of overlap between the transmitted and received beams. This is called range ambiguity, which is the inability to distinguish the absolute depth where the Doppler shift was created. |
| 510. The duty cycle of the continuous wave is 100%.                                                                                                                                            | <b>True.</b> The duty cycle is the percentage of time that the ultrasound transducer is producing sound. With CW Doppler, one crystal is transmitting continuously and the duty cycle is 100%.                                                                                                                                        |



| Questions                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                           |
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| <p>511. All of the following are related to dedicated continuous wave Doppler transducers <i>except</i></p> <ul style="list-style-type: none"> <li>A. wide bandwidth</li> <li>B. high quality factor</li> <li>C. higher sensitivity</li> <li>D. range ambiguity</li> </ul>                | <p><b>A.</b> Continuous wave transducers have a narrow bandwidth. Backing material in pulsed wave transducers creates a wide bandwidth. Since dedicated continuous wave transducers do not use backing material, they have a narrow bandwidth.</p>                                                                                                                |
| <p>512. A duplex ultrasound system displays ____ information.</p> <ul style="list-style-type: none"> <li>A. M-mode, two-dimensional image, and A-mode</li> <li>B. A-mode and B-mode</li> <li>C. two-dimensional image and Doppler</li> <li>D. two-dimensional image and M-mode</li> </ul> | <p><b>C.</b> A duplex scanner displays both Doppler and two-dimensional image data.</p>                                                                                                                                                                                                                                                                           |
| <p>513. All of the following are associated with a CW Doppler transducer <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. narrow bandwidth</li> <li>B. increased sensitivity</li> <li>C. backing material</li> <li>D. high Q-factor</li> </ul>                                | <p><b>C.</b> Compared to pulsed transducers, continuous wave transducers do not use backing material. As a result, CW has increased sensitivity and is more able to detect small Doppler shifts.</p>                                                                                                                                                              |
| <p>514. The information that is processed by a standard duplex ultrasound system includes all of the following <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. attenuation</li> <li>B. amplitude</li> <li>C. frequency</li> <li>D. time of arrival</li> </ul>                | <p><b>A.</b> A duplex ultrasound system provides both image and Doppler information. Included in the data processing is the amplitude of the reflected signal, its time of arrival, and its frequency content. The pulse's attenuation is not recorded or processed.</p>                                                                                          |
| <p>515. True or False? The appearance of negative velocities in a pulsed Doppler display always indicates that red blood cells are moving away from the transducer.</p>                                                                                                                   | <p><b>False.</b> Negative velocities on the spectral display of a pulse Doppler exam may indeed indicate that red blood cells are traveling away from the transducer.</p> <p>However, aliasing may also cause negative velocities in the spectrum. Aliasing occurs when very high Doppler shifts are processed incorrectly as flow in the opposite direction.</p> |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                     |
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| <p>516. With pulsed Doppler, what term is used to describe a very high positive Doppler shift that is displayed as a negative waveform?</p> <ul style="list-style-type: none"> <li>A. attenuation</li> <li>B. filtering</li> <li>C. demodulation</li> <li>D. aliasing</li> </ul>                                                                                                                                          | <p><b>D.</b> In pulsed Doppler exams, the phenomenon where high velocities are displayed as negative velocities is called aliasing. The term alias means "having a false identity".</p>                                                                     |
| <p>517. The highest Doppler frequency without the appearance of aliasing is called the ____ and is equal to ____.</p> <ul style="list-style-type: none"> <li>A. aliasing limit, half of the emitted frequency</li> <li>B. pulse repetition frequency, the pulse repetition frequency</li> <li>C. Nyquist limit, half of the emitted frequency</li> <li>D. Nyquist limit, half of the emitted PRF</li> </ul>               | <p><b>D.</b> The Nyquist limit is the highest Doppler shift that can be displayed without aliasing. The Nyquist limit is equal to half of the pulse repetition frequency (PRF).</p>                                                                         |
| <p>518. True or False? In a pulsed Doppler exam, the use of a higher transducer frequency increases the likelihood that aliasing will appear.</p>                                                                                                                                                                                                                                                                         | <p><b>True.</b> The Doppler shift depends on the frequency of the incident sound wave. The statement is true because a higher emitted frequency produces a higher Doppler shift, and a high Doppler shift is more likely to alias.</p>                      |
| <p>519. True or False? The higher the pulse repetition frequency of a Doppler exam, the more likely aliasing is to occur.</p>                                                                                                                                                                                                                                                                                             | <p><b>False.</b> Aliasing is less likely to occur with high PRF. Aliasing occurs when the Doppler frequency exceeds half of the PRF. If the PRF is high, it is less likely that the Doppler shift will reach a value that is greater than half the PRF.</p> |
| <p>520. A system has three transducers with frequencies of 7.5 MHz, 5 MHz, and 3.25 MHz. Aliasing appears while using the 5.0 MHz transducer during a pulsed Doppler exam. What should the sonographer do?</p> <ul style="list-style-type: none"> <li>A. use the 3.25 MHz transducer</li> <li>B. use the 7.5 MHz transducer</li> <li>C. nothing; the other transducers do not provide solutions to the problem</li> </ul> | <p><b>A.</b> A transducer producing ultrasound at a lower frequency will produce smaller Doppler shifts, which are less likely to alias. Thus, one potential solution for aliasing is to use a lower frequency transducer.</p>                              |

| Questions                                                                                                                                                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
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| <p>521. The frequency of a pulsed Doppler wave is 6 MHz, and the PRF is 5 kHz. What is the maximum Doppler shift that can be recorded without aliasing?</p> <p>A. 6 MHz<br/>B. 5 kHz<br/>C. 3 MHz<br/>D. 2.5 kHz</p>                                                                                                                                                                                | <p><b>D.</b> The frequency at which aliasing occurs is called the Nyquist limit and is one-half the pulse repetition frequency. In this example, the pulse repetition frequency is 5 kHz or 5,000 pulses/sec. Thus, the Nyquist limit is 2.5 kHz. Aliasing will occur when Doppler frequencies exceed this value.</p>                                                                                                                                                                                           |
| <p>522. During a pulsed Doppler exam, aliasing is observed. All of the following may eliminate aliasing <i>except</i>:</p> <p>A. selection of another imaging view with a shallower sample volume<br/>B. selection of another transducer with a lower frequency<br/>C. selection of another imaging view that provides a greater pulse repetition period<br/>D. use of a continuous wave system</p> | <p><b>C.</b> The actions that will reduce the likelihood of aliasing are:</p> <ol style="list-style-type: none"> <li>1. selecting a shallower imaging depth to increase the PRF</li> <li>2. using a transducer with a lower frequency, and</li> <li>3. using a continuous wave Doppler system that cannot alias</li> </ol> <p>If the sonographer selects an imaging view with a greater pulse repetition period, the pulse repetition frequency will decrease and the likelihood of aliasing will increase.</p> |
| <p>523. True or False? TGC cannot be used with continuous wave Doppler.</p>                                                                                                                                                                                                                                                                                                                         | <p><b>True.</b> CW Doppler is not associated with TGC. Unlike pulsed ultrasound, attenuation effects cannot be remedied with continuous wave Doppler.</p>                                                                                                                                                                                                                                                                                                                                                       |
| <p>524. Which of the following determines the gray scale in a Doppler spectrum?</p> <p>A. number of reflectors<br/>B. velocity<br/>C. frequency shift<br/>D. laminar flow</p>                                                                                                                                                                                                                       | <p><b>A.</b> Gray scale in a Doppler spectrum is related to the number of red blood cells creating the reflection.</p>                                                                                                                                                                                                                                                                                                                                                                                          |
| <p>525. Which choice relates to the presence of gray shades in a Doppler spectrum?</p> <p>A. velocity<br/>B. frequency shift<br/>C. amplitude of the echo<br/>D. laminar flow</p>                                                                                                                                                                                                                   | <p><b>C.</b> Gray scale in a Doppler spectrum is related to the number of red blood cells creating the reflection. The number of red blood cells determines the amplitude of the reflected signal.</p>                                                                                                                                                                                                                                                                                                          |



| Questions                                                                                                                                             | Answers                                                                                                                                                                                                                                                                                                                                                               |
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| 526. True or False? Color flow Doppler exams tend to have lower temporal resolution than traditional two-dimensional, real-time imaging.              | <b>True.</b> Temporal resolution is the ability to accurately locate moving structures. Color flow technology reduces the number of pictures produced each second. Color flow Doppler suffers from poor temporal resolution because of this low frame rate.                                                                                                           |
| 527. True or False? Color flow Doppler imaging incorporates pulsed Doppler principles and provides range resolution.                                  | <b>True.</b> One of the greatest advantages of color flow Doppler is its ability to superimpose two-dimensional color velocities upon a two-dimensional gray scale image of anatomy. Color flow Doppler provides range resolution and is based on pulsed Doppler principles.                                                                                          |
| 528. True or False? Color flow Doppler relies on pulsed Doppler principles and is immune to aliasing artifact.                                        | <b>False.</b> The first portion of the statement is true: color flow does indeed rely on pulsed Doppler principles. However, the second part of the statement is false. It is continuous wave Doppler, not pulsed Doppler, that is immune to aliasing.                                                                                                                |
| 529. True or False? Color flow Doppler systems display anatomical data in gray scale while simultaneously displaying flow information in color.       | <b>True.</b> This is the fundamental process by which color flow mapping works. A two-dimensional black and white image provides data on anatomical structures. A two-dimensional color image is displayed simultaneously on top of the black and white image. The color data deals with the Doppler frequencies produced by moving blood cells in the imaging plane. |
| 530. True or False? On a color Doppler image, red always represents flow toward the transducer, whereas blue indicates flow away from the transducer. | <b>False.</b> Although this statement may be true, it is not always true. The color associated with flow toward the transducer appears in the upper half of the color map. The color associated with flow away from the transducer appears in the lower portion of the color map.                                                                                     |

| Questions                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                 |
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| 531. True or False? Absence of color on a color Doppler image always indicates a region of no blood flow.                                                                        | <b>False.</b> Although this statement may be true, it is not always true. Even with blood flow, if the direction of the sound beam is $90^\circ$ to the direction of blood flow, no Doppler shift will be created. The region will remain colorless even when flow is present.                                                                                                                                                          |
| 532. The two most common color maps used in color flow imaging are:<br>A. variance and direct<br>B. variance and velocity<br>C. turbulence and variance<br>D. power and velocity | <b>B.</b> Two common modes of color Doppler are velocity and variance modes.                                                                                                                                                                                                                                                                                                                                                            |
| 533. True or False? Variance mode color maps may be identified by side-to-side changes in the color bar, whereas velocity mode color maps only change color vertically.          | <b>True.</b> Variance mode maps change colors side to side as well as from top to bottom. Velocity mode maps only change color from top to bottom.                                                                                                                                                                                                                                                                                      |
| 534. True or False? Velocity mode color Doppler and variance mode color Doppler will produce identical images when blood flow patterns are laminar.                              | <b>True.</b> The principal difference between velocity and variance modes is that variance mode maps identify turbulent flow. Turbulent flow appears on the image as a third color, such as green, that is located on the right side of the color map. If turbulent flow is not present, then the third color will not appear on the image and the velocity and variance mode images will look identical.                               |
| 535. True or False? Velocity mode color Doppler and variance mode color Doppler will produce identical images when blood flow patterns are turbulent.                            | <b>False.</b> The principal difference between velocity and variance modes is that variance mode maps are able to identify turbulent flow. Turbulent flow appears on the image as a third color, such as green, that is located on the right side of the color map. When turbulent flow exists, the variance color will appear. Since there is no variance color with velocity mode, the variance and velocity mode images will differ. |

| Questions                                                                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                                                                                                                                     |
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| <b>ARTIFACTS</b>                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                             |
| <p>536. While using a linear sequential array transducer during a color Doppler exam, the shape of the gray scale image is most often _____, whereas the shape of the color Doppler portion of the image is _____.</p> <p>A. rectangular, parallelogram<br/>B. rectangular, sector<br/>C. sector, trapezoid<br/>D. square, rectangular</p>                                      | <p>A. The shape of a gray scale image using a linear sequential array is rectangular. However, the sound beams used for Doppler are steered at an angle, creating a parallelogram-shaped region.</p>                                                                                                                                        |
| <p>537. What is the meaning of the term "analysis" in the context of spectral analysis of Doppler signals?</p> <p>A. building a sophisticated signal from components<br/>B. building a simplified signal from components<br/>C. identifying the building blocks or components of a complex signal<br/>D. measuring a complex signal, then modifying its information content</p> | <p>C. The term <i>analysis</i> defines the act of scrutinizing an object to determine what individual components are incorporated within it. In Doppler analysis, the complex signal is broken down into its more basic ingredients.</p>                                                                                                    |
| <p>538. The analysis of Doppler spectra using _____ is most accurate.</p> <p>A. zero-crossing detectors<br/>B. Fast Fourier Transforms<br/>C. time interval histograms<br/>D. Chirp-Z transforms</p>                                                                                                                                                                            | <p>B. The Fast Fourier Transform, or FFT, is the most accurate spectral analysis technique. Techniques such as zero-crossing, time interval histograms, and Chirp-Z were initially used to assess Doppler spectra, but are now obsolete. Fast Fourier analysis became popular when computers were incorporated into ultrasound systems.</p> |
| <p>539. Spectral analysis of color flow Doppler is most commonly performed by which of the following techniques?</p> <p>A. zero-crossing detectors<br/>B. Fast Fourier transforms<br/>C. autocorrelation<br/>D. Chirp-Z transforms</p>                                                                                                                                          | <p>C. Autocorrelation is the technique of choice for spectral analysis of color Doppler. Although the most accurate technique is the FFT, autocorrelation is better suited to process the enormous amount of data acquired in a color Doppler study.</p>                                                                                    |



| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                    |
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| <p>540. Acoustic artifacts include: (More than one answer may be correct.)</p> <ul style="list-style-type: none"> <li>A. images of reflectors in an inappropriate position</li> <li>B. images of reflectors with improper shape</li> <li>C. images of reflectors with incorrect brightness</li> <li>D. images that do not correspond to anatomical structures</li> </ul>                                                                                                          | <p><b>A, B, C, and D.</b></p> <p>An artifact is an error in imaging. All of the choices indicate a type of error, and therefore, are artifacts.</p>                                                                        |
| <p>541. Which of the following is not a potential cause of artifact in diagnostic imaging?</p> <ul style="list-style-type: none"> <li>A. operator error</li> <li>B. equipment malfunction</li> <li>C. patient motion</li> <li>D. ultrasound physics</li> <li>E. none of the above</li> </ul>                                                                                                                                                                                      | <p><b>E.</b> The four choices, A through D, represent the primary explanations of artifacts commonly seen in diagnostic ultrasound.</p>                                                                                    |
| <p>542. Ultrasound systems are designed to automatically ____.</p> <ul style="list-style-type: none"> <li>A. display similar structures with equal brightness, regardless of depth</li> <li>B. position structures at the correct depth, regardless of the medium</li> <li>C. display all reflections on a line corresponding to the main axis of the sound beam, regardless of refraction</li> <li>D. select the optimal beam width based on the clinical application</li> </ul> | <p><b>C.</b> Ultrasound systems assume that all reflections are created from reflectors that lie directly along the main axis of the ultrasound beam. An artifact is created when pulses refract and change direction.</p> |
| <p>543. Six distinct, equally spaced reflections appear on an image at ever increasing depths. What type of artifact is this?</p> <ul style="list-style-type: none"> <li>A. reverberation</li> <li>B. ring down</li> <li>C. mirror imaging</li> <li>D. longitudinal resolution</li> </ul>                                                                                                                                                                                         | <p><b>A.</b> Reverberations are multiple, equally spaced reflections.</p>                                                                                                                                                  |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                         |
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| <p>544. Which situation will commonly produce reverberation artifact?</p> <ul style="list-style-type: none"> <li>A. two masses that lie perpendicular to the sound beam's main axis</li> <li>B. two weak reflectors that lie close to each other along the axis of the beam</li> <li>C. two strong reflectors that lie along the main axis of the beam</li> <li>D. a single highly reflective mass</li> </ul>         | <p>C. Reverberations are commonly produced by a pair of strong reflectors that lie along the main axis of an ultrasound beam.</p>                                                                                                               |
| <p>545. What are the characteristics of a medium that produces comet tail artifact?</p> <ul style="list-style-type: none"> <li>A. weak reflectors, closely spaced, low propagation speeds</li> <li>B. strong reflectors, widely spaced, high propagation speeds</li> <li>C. strong reflectors, closely spaced, low propagation speed</li> <li>D. strong reflectors, closely spaced, high propagation speed</li> </ul> | <p>D. A comet tail artifact is similar to a reverberation except that the reflection is a solid hyperechoic line.</p> <p>The comet tail is a solid jet because of strong reflectors with high propagation speeds lying close to each other.</p> |
| <p>546. What is the most likely cause of ring down artifact?</p> <ul style="list-style-type: none"> <li>A. refraction</li> <li>B. inversion</li> <li>C. reabsorption</li> <li>D. reflection</li> </ul>                                                                                                                                                                                                                | <p>D. Ring down artifact is thought to result from multiple reflections.</p>                                                                                                                                                                    |
| <p>547. Where are shadowing artifacts commonly seen on an acoustic scan?</p> <ul style="list-style-type: none"> <li>A. deeper than a structure with a high impedance</li> <li>B. shallower than a structure with a low propagation speed</li> <li>C. deeper than a structure with a high attenuation</li> <li>D. alongside of a structure with a low elastance</li> </ul>                                             | <p>C. Shadowing occurs on an image at locations beneath strong attenuators. For example, a region deeper than a gallstone may be affected by shadowing.</p>                                                                                     |

| Questions                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                                                                               |
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| <p>548. How is shadowing artifact expressed?</p> <ul style="list-style-type: none"> <li>A. positioning structures too deep on the image</li> <li>B. locating structures in improper lateral position</li> <li>C. placing reflections in multiple locations</li> <li>D. reflectors being absent on the image</li> </ul> | <p>D. A shadow artifact results from unexpectedly high attenuation. The ultrasound beam deeper than the strong attenuator is so weak that significant anatomical information does not appear on the image.</p>                                        |
| <p>549. Which of these produces shadowing?</p> <ul style="list-style-type: none"> <li>A. reverberation</li> <li>B. multipath</li> <li>C. reflection</li> <li>D. attenuation</li> </ul>                                                                                                                                 | <p>D. Shadowing results from atypical attenuation, the weakening of ultrasound pulses.</p>                                                                                                                                                            |
| <p>550. What causes enhancement artifact?</p> <ul style="list-style-type: none"> <li>A. sound beams bending</li> <li>B. linear array transducer architecture</li> <li>C. unexpectedly low acoustic attenuation</li> <li>D. acoustic energy radiating in a direction other than the beam's main axis</li> </ul>         | <p>C. Enhancement artifact appears directly below structures with atypically low attenuation. Cystic structures often create enhancement artifact since fluids within the cyst often attenuate sound to a lesser extent than surrounding tissues.</p> |
| <p>551. Unexpectedly low attenuation results in which of the artifacts listed below?</p> <ul style="list-style-type: none"> <li>A. refraction</li> <li>B. attenuation</li> <li>C. enhancement</li> <li>D. shadowing</li> </ul>                                                                                         | <p>C. Enhancement occurs with unexpectedly low rates of attenuation.</p>                                                                                                                                                                              |
| <p>552. When enhancement occurs, where does it appear on the image?</p> <ul style="list-style-type: none"> <li>A. in the near field</li> <li>B. deeper than a weak attenuator</li> <li>C. in the far field</li> <li>D. shallower than a weak reflector</li> </ul>                                                      | <p>B. Enhancement occurs after an ultrasound pulse has traveled through a low attenuating tissue and appears on the image deeper (distal) than that structure.</p>                                                                                    |



| Questions                                                                                                                                                                                                                                                                                                                                    | Answers                                                                                                                                                                                                                                                                                                 |
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| <p>553. Acoustic focusing of an ultrasound beam may create which artifact?</p> <ul style="list-style-type: none"> <li>A. side lobes</li> <li>B. refraction</li> <li>C. speckle</li> <li>D. enhancement</li> </ul>                                                                                                                            | <p><b>D.</b> Focusing of an ultrasound beam may result in very strong reflections from anatomic structures at the depth of the focus. The powerful reflections result in a hyperechoic band that is called focal enhancement or focal banding.</p>                                                      |
| <p>554. Which process causes mirror image artifact?</p> <ul style="list-style-type: none"> <li>A. reflection</li> <li>B. refraction</li> <li>C. propagation speed error</li> <li>D. attenuation</li> </ul>                                                                                                                                   | <p><b>A.</b> Mirror imaging is created by an unexpected and uncorrected reflection of the ultrasound pulse off a strong reflector.</p>                                                                                                                                                                  |
| <p>555. Where is a mirror image artifact located?</p> <ul style="list-style-type: none"> <li>A. sometimes shallower on the image than in the body</li> <li>B. always deeper on the image than in the body</li> <li>C. sometimes the same depth on the image as in the body</li> <li>D. never deeper on the image than in the body</li> </ul> | <p><b>B.</b> A mirror image artifact occurs when a pulse bounces off a strong reflector (such as the diaphragm) and then strikes a second reflector.</p> <p>The pulse's path is lengthened by the mirroring, and the second reflection (artifact) is always displayed at an abnormally great depth.</p> |
| <p>556. Which artifact is not affected by the shape or dimensions of an ultrasound pulse?</p> <ul style="list-style-type: none"> <li>A. lateral resolution</li> <li>B. slice thickness</li> <li>C. mirror imaging</li> <li>D. longitudinal resolution</li> </ul>                                                                             | <p><b>C.</b> Of the artifacts listed, only mirror imaging is unrelated to the size, shape, or geometry of the ultrasound pulse. The others depend in some way on the pulse's characteristics.</p>                                                                                                       |
| <p>557. Which artifact is created by sound moving through a medium with a propagation speed less than soft tissue?</p> <ul style="list-style-type: none"> <li>A. vertical misregistration</li> <li>B. horizontal misregistration</li> <li>C. lateral resolution</li> <li>D. ring down</li> </ul>                                             | <p><b>A.</b> Vertical misregistration occurs when pulses do not travel at the speed of sound in soft tissue (1,540 m/sec.) The reflections on the image will be placed at depths deeper than the actual position of the reflector in the body.</p>                                                      |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                                                                                                                                                    |
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| <p>558. While imaging a test object, an ultrasound system displays one image 1.8 cm deeper than another. Upon measuring the test object, it is found that it is actually 2.0 cm deeper. What conclusion can be drawn from this?</p> <ul style="list-style-type: none"> <li>A. speed of sound in the test object is the same as soft tissue</li> <li>B. speed in the test object is less than that in soft tissue</li> <li>C. attenuation of sound in the test object is less than that in soft tissue</li> <li>D. speed in soft tissue is less than that of the test object</li> </ul> | <p>D. When vertical misregistration occurs, it is likely that the speed of sound in the medium differs from 1,540 m/sec. If the measurements on the image are less than the true distances, then the speed of sound in the medium is greater than that of soft tissue.</p>                                                 |
| <p>559. If an ultrasound pulse travels through a large mass in the body at a speed of 1.2 mm/<math>\mu</math>s, what happens to the position of all echoes produced from reflectors shallower than the mass?</p> <ul style="list-style-type: none"> <li>A. they are placed in too shallow a location on the image</li> <li>B. they are placed in too deep a location on the image</li> <li>C. they are likely to be placed at the correct depth</li> </ul>                                                                                                                             | <p>C. The mass has a propagation speed different than that of soft tissue. Only structures deeper than the mass will be affected.</p> <p>However, this question asks about reflectors that are shallower than the mass. Reflections from structures shallower than the mass are not affected by this speed difference.</p> |
| <p>560. If a sound pulse travels through a large mass at a speed of 1.2 mm/<math>\mu</math>s, what happens to the position of echoes from reflectors deeper than the mass?</p> <ul style="list-style-type: none"> <li>A. they are placed in too shallow a location on the image</li> <li>B. they are placed in too deep a location on the image</li> <li>C. they are likely to be placed at the correct depth</li> </ul>                                                                                                                                                               | <p>B. The mass has a slow propagation speed when compared with soft tissue. All structures distal to the mass will be placed at too great a depth on the image. The reflections on the image will be farther than the reflector's true anatomical position.</p>                                                            |

| Questions                                                                                                                                                                                                                                                                                                                                                                              | Answers                                                                                                                                                                                             |
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| <p>561. What type of artifact causes a reflection to be placed at an incorrect depth?</p> <ul style="list-style-type: none"> <li>A. lateral incertitude</li> <li>B. shadowing</li> <li>C. range ambiguity</li> <li>D. indeterminate relaxation</li> </ul>                                                                                                                              | <p>C. Range ambiguity means that uncertainty exists regarding the depth of a structure in the body.</p>                                                                                             |
| <p>562. What causes side lobe artifact?</p> <ul style="list-style-type: none"> <li>A. sound beams bending</li> <li>B. linear array transducer architecture</li> <li>C. unexpectedly low acoustic attenuation</li> <li>D. acoustic energy radiating in a direction other than the beam's main axis</li> </ul>                                                                           | <p>D. A side lobe is produced when a significant amount of acoustic energy is directed along a line other than the main axis of the acoustic pulse.</p>                                             |
| <p>563. Side lobe artifact usually results in all of the following except ____.</p> <ul style="list-style-type: none"> <li>A. hollow structures appearing "filled in" on the image</li> <li>B. reflectors not appearing on an image</li> <li>C. reflectors appearing in improper locations on the image</li> <li>D. reflectors appearing in multiple locations on the image</li> </ul> | <p>B. It is unlikely that a side lobe artifact would result in the absence of a reflector on an image. With side lobes, it is more likely that additional reflections will appear on the image.</p> |
| <p>564. Grating lobes are most common with which type of transducer technology?</p> <ul style="list-style-type: none"> <li>A. annular array</li> <li>B. continuous wave</li> <li>C. mechanical scanners</li> <li>D. linear arrays</li> </ul>                                                                                                                                           | <p>D. Grating lobe artifacts are associated with linear array transducers.</p>                                                                                                                      |
| <p>565. Grating lobes are produced by the same mechanism as which other artifact?</p> <ul style="list-style-type: none"> <li>A. side lobes</li> <li>B. reverberation</li> <li>C. transaxial lobes</li> <li>D. acoustic speckle</li> </ul>                                                                                                                                              | <p>A. Side lobes and grating lobes are similar in that they represent acoustic energy transmission in a direction other than the main axis of an acoustic beam.</p>                                 |



| Questions                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                                                                                                                                                      |
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| 566. True or False? Grating lobes are a result of substantial acoustic energy directed outward from a linear array transducer, but not along the main axis of the sound beam.                                                                                                   | <b>True.</b> This is the exact definition of a grating lobe.                                                                                                                                                                                                                                                                                 |
| 567. Which technique of linear array transducer design has virtually eliminated the appearance of grating lobe artifact on modern ultrasound systems?<br>A. demodulation<br>B. subdicing<br>C. deconvolution<br>D. none of the above                                            | <b>B.</b> The process of subdicing has almost eliminated the appearance of grating lobe artifact on linear array transducer systems. Subdicing consists of dividing each of the crystals in the array into smaller pieces. The subdiced pieces are then fired simultaneously as if they were a single crystal. This minimizes grating lobes. |
| 568. True or False? Grating lobes are attributed only to array transducers.                                                                                                                                                                                                     | <b>True.</b> Grating lobes are associated with array transducers.                                                                                                                                                                                                                                                                            |
| 569. Which artifact results in improper side-by-side positioning of reflectors?<br>A. multipath<br>B. comet tail<br>C. refraction<br>D. reverberation                                                                                                                           | <b>C.</b> Refraction artifact results from an acoustic pulse bending and changing direction. This change of direction is not corrected by the ultrasound system and results in an improper lateral location of reflectors on the image.                                                                                                      |
| 570. What assumption is violated when a refracted sound wave is processed?<br>A. waves travel directly to and from a reflector<br>B. sound travels at an average speed of 1.54 mm/ $\mu$ s<br>C. sound travels in a straight line<br>D. the acoustic imaging plane is very thin | <b>C.</b> Ultrasound systems create images on the basis of certain assumptions. Artifacts occur when these assumptions are invalid. Refraction artifact results from sound traveling in a crooked or bent line while the ultrasound system assumes a straight path.                                                                          |
| 571. With standard diagnostic imaging instrumentation, which has the higher numerical value?<br>A. axial resolution<br>B. lateral resolution<br>C. elevational resolution                                                                                                       | <b>C.</b> In terms of image accuracy, elevational resolution, determined by slice thickness, is the cause of greatest image degradation. The numerical value assigned to elevational resolution is higher than the others.                                                                                                                   |

| Questions                                                                                                                                                                                                                                                                                        | Answers                                                                                                                                                                                                                                                                                                                                          |
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| <p>572. What artifact results from an ultrasound beam having a finite and measurable three-dimensional profile?</p> <ul style="list-style-type: none"><li>A. acoustic speckle</li><li>B. multipath artifact</li><li>C. slice thickness artifact</li><li>D. grating lobe artifact</li></ul>       | <p>C. Slice artifact occurs because a sound beam has a thickness. Although the sonographer imagines that the imaging plane is extremely thin, the beam actually has a measurable thickness. Thickness artifact results in some reflectors appearing in the image even though they are positioned above or below the idealized imaging plane.</p> |
| <p>573. How does slice thickness artifact commonly express itself?</p> <ul style="list-style-type: none"><li>A. fill in of cystic structures</li><li>B. improper brightness of reflectors</li><li>C. absence of reflectors</li><li>D. strong linear echoes</li></ul>                             | <p>A. Slice thickness artifact results in reflections placed on the image that do not correlate with the anatomical position of the reflector. Therefore, anechoic structures in the imaging plane are filled in with echoes from structures above or below the image slice.</p>                                                                 |
| <p>574. With depth resolution, _____.</p> <ul style="list-style-type: none"><li>A. too many reflectors appear on the image</li><li>B. reflectors are placed too deep on the image</li><li>C. too few reflectors are on the image</li><li>D. reflectors appear too shallow on the image</li></ul> | <p>C. Depth resolution is the ability to distinguish two reflectors that lie close to each other along the main axis of the beam. Most errors in depth resolution result in fewer reflections placed on the image than are actually in the body. Depth resolution is another name for axial resolution.</p>                                      |
| <p>575. Axial resolution artifacts are due to which of the following?</p> <ul style="list-style-type: none"><li>A. multiple reflections</li><li>B. beam width</li><li>C. attenuation</li><li>D. pulse length</li></ul>                                                                           | <p>D. The critical factor that influences axial resolution is pulse length. Shorter pulses produce more accurate images than longer pulses. Shorter pulses have improved axial resolution.</p>                                                                                                                                                   |

| Questions                                                                                                                                                                                                                                                                                                                                                                    | Answers                                                                                                                                                                                                                                                                                                     |
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| <p>576. Which of these pulses is least likely to produce an axial resolution artifact?</p> <ul style="list-style-type: none"> <li>A. 10 MHz, 8 mm beam diameter, 6 cycles per pulse</li> <li>B. 4 MHz, 4 mm beam diameter, 2 cycles per pulse</li> <li>C. 9 MHz, 8 mm beam diameter, 2 cycles per pulse</li> <li>D. 6 MHz, 2 mm beam diameter, 2 cycles per pulse</li> </ul> | <p><b>C.</b> Short pulses are least likely to produce an axial resolution artifact. Short pulses are those with a high frequency and few cycles per pulse.</p> <p>Although choice C does not have the highest frequency, it has only 2 cycles per pulse, and therefore is the shortest of the 4 pulses.</p> |
| <p>577. With which of the following pulses would lateral resolution be worst?</p> <ul style="list-style-type: none"> <li>A. 10 MHz, 4 mm beam diameter, 4 cycles per pulse</li> <li>B. 4 MHz, 4 mm beam diameter, 2 cycles per pulse</li> <li>C. 7.5 MHz, 8 mm beam diameter, 2 cycles per pulse</li> <li>D. 6 MHz, 2 mm beam diameter, 2 cycles per pulse</li> </ul>        | <p><b>C.</b> Lateral resolution artifact is related to the diameter of the ultrasound beam. Narrow beams have the best lateral resolution. Wide beams have the worst lateral resolution.</p> <p>Choice C, with a beam diameter of 8 mm, is most likely to produce a lateral resolution artifact.</p>        |
| <p>578. The lateral resolution of four ultrasound systems appear below. Which will produce the finest quality picture?</p> <ul style="list-style-type: none"> <li>A. 2 cm</li> <li>B. 4 mm</li> <li>C. 6 mm</li> <li>D. 8 mm</li> </ul>                                                                                                                                      | <p><b>B.</b> Resolution is reported in units of distance, with smaller values producing higher quality pictures.</p> <p>Choice B is the smallest number and therefore represents the system with the best images based on lateral resolution.</p>                                                           |
| <p>579. Two small cysts, positioned perpendicular to the main axis of a sound beam, are 2.4 mm apart. What determines whether they appear as two distinct images on the system's display?</p> <ul style="list-style-type: none"> <li>A. the beam width</li> <li>B. the pulse length</li> <li>C. the PRF</li> <li>D. the TGC</li> </ul>                                       | <p><b>A.</b> The ability to correctly image structures that lie close to each other in a direction perpendicular to the main axis of the ultrasound beam is called lateral resolution. Lateral resolution is primarily determined by the width of the acoustic pulse.</p>                                   |



| Questions                                                                                                                                                                                                                                                | Answers                                                                                                                                                                                                                                                                                                                                      |
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| <p>580. Which artifact is not related to the unexpected reflection of an acoustic wave?</p> <ul style="list-style-type: none"> <li>A. multipath</li> <li>B. comet tail</li> <li>C. reverberation</li> <li>D. lateral resolution</li> </ul>               | <p><b>D.</b> Lateral resolution is an artifact that is not associated with abnormal reflection. Lateral resolution artifacts are related to beam diameter.</p>                                                                                                                                                                               |
| <p>581. True or False? Side lobe, grating lobe, and refraction artifacts all reduce lateral resolution.</p>                                                                                                                                              | <p><b>True.</b> Lateral resolution is related to structures that lie in a plane perpendicular to the sound beam's main axis. These three artifacts all degrade lateral resolution.</p>                                                                                                                                                       |
| <p>582. True or False? Artifacts are likely to appear when the dimensions of the sound beam area are larger than the dimensions of the reflectors in the body.</p>                                                                                       | <p><b>True.</b> Artifacts are created for many reasons. Some artifacts, such as slice thickness and axial resolution, result from the sound beam being larger than the reflectors.</p>                                                                                                                                                       |
| <p>583. True or False? All artifacts are errors in imaging that do not represent the true anatomy of the imaged organ. Therefore, they are all undesirable and should be eliminated if possible.</p>                                                     | <p><b>False.</b> All artifacts are indeed errors in imaging. However, they may provide useful information. An artifact can provide insight into the physical characteristics of a structure, and help the clinician make a definitive diagnosis. Eliminating all artifacts may exclude important information from appearing on the exam.</p> |
| <p>584. With standard diagnostic imaging instrumentation, which has the higher numerical value?</p> <ul style="list-style-type: none"> <li>A. axial resolution</li> <li>B. lateral resolution</li> <li>C. neither; they have identical values</li> </ul> | <p><b>B.</b> In terms of image accuracy, axial resolution is usually better than lateral resolution. The number assigned to lateral resolution is higher than to axial resolution.</p>                                                                                                                                                       |
| <p>585. What is a comet tail artifact's fundamental mechanism of formation?</p> <ul style="list-style-type: none"> <li>A. reflection</li> <li>B. rarefaction</li> <li>C. refraction</li> <li>D. attenuation</li> </ul>                                   | <p><b>A.</b> Comet tail artifacts appear on an image as a result of numerous reflections between two closely spaced reflectors.</p>                                                                                                                                                                                                          |

| Questions                                                                                                                                                                                                                                                                                                                       | Answers                                                                                                                                                                                                       |
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| <p>586. In diagnostic imaging, how does multipath artifact affect the image?</p> <ul style="list-style-type: none"> <li>A. poor angular resolution</li> <li>B. creation of hyperechoic regions</li> <li>C. mild image degradation</li> <li>D. gross horizontal misregistration</li> </ul>                                       | <p><b>C.</b> Multipath artifact does not manifest itself in a pronounced manner. The primary result of this artifact is mild image degradation.</p>                                                           |
| <p>587. Which of the following determines the spatial resolution of an image on a monitor?</p> <ul style="list-style-type: none"> <li>A. strength of the electron beam</li> <li>B. form of phosphor coating of the screen</li> <li>C. number of lines of the monitor's display</li> <li>D. the pulse duration</li> </ul>        | <p><b>C.</b> The image displayed on a monitor is composed of a number of horizontal lines. The detail within the image, called spatial resolution, is determined by the number of TV lines on the screen.</p> |
| <p>588. What is the cause of acoustic speckle?</p> <ul style="list-style-type: none"> <li>A. refraction</li> <li>B. attenuation</li> <li>C. interference of tiny acoustic wavelets</li> <li>D. resonance of particles in the near field</li> </ul>                                                                              | <p><b>C.</b> Acoustic speckle is produced by the constructive and destructive interference of small acoustic waves reflected from small reflectors in the near field.</p>                                     |
| <p>589. What is true of acoustic speckle?</p> <ul style="list-style-type: none"> <li>A. its effects are mild and it tends to slightly degrade images</li> <li>B. it is a rare artifact that does not occur in real-time imaging</li> <li>C. its effects are dramatic</li> <li>D. it is eliminated with apolarization</li> </ul> | <p><b>A.</b> Even though it does not accurately represent reflectors in the medium, acoustic speckle is often considered "tissue texture." It tends to contribute to overall image degradation.</p>           |
| QUALITY ASSURANCE                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                               |
| <p>590. True or False? Quality assurance evaluations of ultrasound systems should be performed weekly.</p>                                                                                                                                                                                                                      | <p><b>False.</b> Quality assurance evaluations must be performed routinely. The actual time between evaluations is determined by the pattern of use of the system.</p>                                        |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                                | Answers                                                                                                                                                                                                                                                              |
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| <p>591. True or False? Quality assurance evaluations of ultrasound systems can only be performed by biomedical engineers or physical scientists.</p>                                                                                                                                                                                                                                                                                                     | <p><b>False.</b> Quality assurance evaluations should be performed by the sonographers who use the system. Although other individuals may be capable of evaluating system performance, the sonographer plays an essential role in the quality assurance program.</p> |
| <p>592. True or False? Proper quality assurance programs require the assessment of every transducer used in the clinical laboratory.</p>                                                                                                                                                                                                                                                                                                                 | <p><b>True.</b> To establish a valid and rigorous quality assurance program, each component in clinical use must be evaluated. Thus, each transducer must be individually assessed.</p>                                                                              |
| <p>593. Which of the following statements are true of a tissue equivalent phantom? (More than one answer may be correct.)</p> <ul style="list-style-type: none"> <li>A. it has the same propagation speed as that of soft tissue</li> <li>B. it attenuates ultrasound at a rate similar to soft tissue</li> <li>C. embedded in it are solid masses and cystic structures</li> <li>D. it is the device of choice for quality assurance studies</li> </ul> | <p><b>A, B, C, and D.</b><br/>Tissue equivalent phantoms have characteristics that allow for the optimal evaluation of ultrasound systems. They are quite similar to soft tissue and are the preferred device to evaluate system performance.</p>                    |
| <p>594. All of the following may be used to evaluate Doppler systems <i>except</i>:</p> <ul style="list-style-type: none"> <li>A. tissue equivalent phantom</li> <li>B. moving belt phantom</li> <li>C. vibrating string phantom</li> <li>D. Doppler phantom</li> </ul>                                                                                                                                                                                  | <p><b>A.</b> The tissue equivalent phantom is not suitable for evaluating Doppler systems because all the reflectors within it are stationary. Doppler evaluations require moving reflectors.</p>                                                                    |
| <p>595. Which modes of Doppler may be assessed with a Doppler phantom?</p> <ul style="list-style-type: none"> <li>A. color flow Doppler</li> <li>B. pulsed Doppler</li> <li>C. power mode Doppler</li> <li>D. continuous wave Doppler</li> <li>E. all of the above</li> </ul>                                                                                                                                                                            | <p><b>E.</b> A Doppler phantom is a versatile device that evaluates all Doppler modes including pulsed, continuous wave, color flow, and power mode.</p>                                                                                                             |



| Questions                                                                                                                                                                                                                                                           | Answers                                                                                                                                                                                                                                                                                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BIOEFFECTS</b>                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                       |
| <p>596. Which two of the following devices convert ultrasound energy into heat?</p> <p>A. a calorimeter<br/>B. a thermocouple<br/>C. a hydrophone<br/>D. a Schlieren</p>                                                                                            | <p><b>A and B.</b></p> <p>The calorimeter and the thermocouple are two devices that use the principle of converting acoustic energy into thermal energy to estimate the energy in a sound beam.</p> <p>A hydrophone converts acoustic energy into pressure. A Schlieren uses the interaction of sound and light to evaluate a sound beam profile.</p> |
| <p>597. The _____ measures beam intensity at specific locations, whereas a _____ measures the entire energy in a sound beam.</p> <p>A. calorimeter, thermocouple<br/>B. Schlieren, thermocouple<br/>C. thermocouple, calorimeter<br/>D. thermometer, hydrometer</p> | <p><b>C.</b> The thermocouple is a small electronic thermometer that measures the sound beam's energy at specific locations.</p> <p>The calorimeter absorbs all the beam's energy, converting it to heat. The calorimeter measures all the beam's energy.</p>                                                                                         |
| <p>598. True or False? The biological effects of ultrasound are thought to be negligible and thus, few investigations have been performed on the subject.</p>                                                                                                       | <p><b>False.</b> The biological effects of ultrasound are studied extensively by scientists throughout the world. Under specific circumstances, bioeffects have been confirmed and are the subject of many discussions, investigations, and publications.</p>                                                                                         |
| <p>599. True or False? It is generally believed that the effects of ultrasound on biologic media are minimal.</p>                                                                                                                                                   | <p><b>False.</b> Ultrasonic bioeffects are substantial under certain conditions, including, but not limited to, therapeutic ultrasound and lithotripsy.</p>                                                                                                                                                                                           |
| <p>600. Under which condition is it permissible to perform a diagnostic ultrasound exam?</p> <p>A. when the patient will benefit<br/>B. when the patient has insurance<br/>C. when the exam is perfectly safe<br/>D. when the benefits outweigh the risks</p>       | <p><b>D.</b> It is proper to perform a diagnostic ultrasound exam when the benefit to the patient outweighs the risks that may be present.</p>                                                                                                                                                                                                        |

| Questions                                                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>601. Some ultrasonic bioeffects studies are performed <i>in vivo</i>. What is the meaning of the term <i>in vivo</i>?</p> <p>A. observable in a living body<br/>B. observations based on an experiment<br/>C. discernible in a test tube<br/>D. estimated in a computer simulation</p> | <p>A. <i>In vivo</i> observations are made in a living body. For example, increased tissue temperatures in patients following exposure to ultrasound are considered <i>in vivo</i> observations.</p>                                                                                                                                                                                                             |
| <p>602. Certain studies of bioeffects are performed <i>in vitro</i>. What is the meaning of <i>in vitro</i>?</p> <p>A. visible in a living organism<br/>B. observations based on experiments<br/>C. discernible in a test tube<br/>D. perceptible in a living human being</p>             | <p>C. An <i>in vitro</i> experiment is performed out of the body and in an artificial environment. The observations may be described as "in a test tube."</p>                                                                                                                                                                                                                                                    |
| <p>603. Which component of an ultrasound system exposes a patient to greatest risk?</p> <p>A. the CRT<br/>B. the electric cord<br/>C. the pulser<br/>D. the transducer</p>                                                                                                                | <p>D. Although the risk is small, the transducer exposes the patient to the greatest risk during an ultrasound scan. However, the risk will be substantially greater if the system is not functioning properly or being used in a responsible manner.</p>                                                                                                                                                        |
| <p>604. True or False? The AIUM suggests that <i>in vitro</i> research confirming bioeffects is valuable and valid. Their results are significant and should be directly applied to the clinical arena.</p>                                                                               | <p><b>False.</b> Although <i>in vitro</i> experiments results are extremely important, it is difficult to assess their direct clinical significance. Further studies should be performed before applying these conclusions clinically.</p>                                                                                                                                                                       |
| <p>605. True or False? The mechanistic approach to the study of bioeffects and safety includes the identification of a theoretical construct that could produce an effect.</p>                                                                                                            | <p><b>True.</b> The mechanistic approach is based on developing a theory as to how something happens. If the theoretical mechanism is proven correct, it provides great insight into the system and its component factors. The development of a computer simulation of tissue temperature and its relation to exposure is such an example.</p> <p>The mechanistic approach is considered "cause and effect."</p> |



| Questions                                                                                                                                                                                                                                                 | Answers                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>606. True or False? The empirical approach to the study of bioeffects and ultrasonic safety surveys data involves finding a relationship between exposure and toxic effects.</p>                                                                       | <p><b>True.</b> An empirical study is one where investigators look for a relationship between two events without necessarily understanding the fundamental cause and effect that relates the two factors. An example of an empirical study is examining the possibility that changes in fetal birth weight and ultrasound exposure are associated. Note that no specific mechanism for this relationship is postulated.</p> <p>The empirical approach is considered "exposure-response."</p> |
| <p>607. True or False? A bioeffect identified through the mechanistic approach rather than the empirical approach is more likely to have clinical significance.</p>                                                                                       | <p><b>False.</b> A bioeffect identified only by a mechanistic methodology is not likely to have greater clinical significance than a bioeffect identified empirically. The most clinically relevant bioeffect would be one identified both mechanistically and empirically.</p>                                                                                                                                                                                                              |
| <p>608. True or False? The AIUM considers an ultrasound-induced biologic tissue temperature rise of less than 2° Centigrade above normal body temperature as safe for clinical studies.</p>                                                               | <p><b>True.</b> AIUM guidelines state that an exam is considered free of the potential for thermally induced bioeffects if the tissue temperature is within 2° C of normal.</p>                                                                                                                                                                                                                                                                                                              |
| <p>609. Which of the following terms best describes the mechanistic investigation of bioeffects?</p> <ul style="list-style-type: none"> <li>A. cause-effect</li> <li>B. exposure-response</li> <li>C. cause-response</li> <li>D. exposure-cure</li> </ul> | <p><b>A.</b> The mechanistic approach to the study of bioeffects is properly called cause and effect.</p> <p>For example, a researcher might propose that vibration causes harmful bioeffects and then conducts research to see whether this is indeed the case.</p>                                                                                                                                                                                                                         |
| <p>610. Which of these terms best describes the empirical investigation of bioeffects?</p> <ul style="list-style-type: none"> <li>A. cause-effect</li> <li>B. exposure-response</li> <li>C. cause-response</li> <li>D. exposure-cure</li> </ul>           | <p><b>B.</b> The empirical approach to the study of bioeffects searches for a biologic response following an exposure to ultrasound.</p> <p>An example of an empirical study is the assessment of a newborn child following an ultrasound study performed while <i>in utero</i>.</p>                                                                                                                                                                                                         |



| Questions                                                                                                                                                                                                                                                                                    | Answers                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>611. When studying bioeffects, which research approach is more important?</p> <ul style="list-style-type: none"> <li>A. empirical</li> <li>B. mechanistic</li> <li>C. neither is important</li> <li>D. both are equally important</li> </ul>                                              | <p><b>D.</b> Both the empirical and the mechanistic approaches are important. The strongest bioeffects conclusions are reached when the results of both approaches are in agreement.</p>                                                                                                                                    |
| <p>612. Of the following choices, which is considered the most important for the sonographer with regard to bioeffects?</p> <ul style="list-style-type: none"> <li>A. pulse repetition frequency</li> <li>B. frequency</li> <li>C. duration of the study</li> <li>D. imaging mode</li> </ul> | <p><b>C.</b> The exam duration is most significant because the sonographer directly controls it. Exams should always be of high quality and should provide relevant diagnostic information with a secondary goal of minimizing output power level and time exposure to the patient.</p>                                     |
| <p>613. Which of the following is <i>not</i> a potential mechanism for production of bioeffects from ultrasound exposure to the body?</p> <ul style="list-style-type: none"> <li>A. temperature elevation</li> <li>B. fractionation</li> <li>C. cavitation</li> <li>D. vibration</li> </ul>  | <p><b>B.</b> Fractionation means "to separate a mixture into its ingredients" and has nothing to do with bioeffects. The other choices are <i>potential</i> mechanisms for acoustic bioeffects.</p>                                                                                                                         |
| <p>614. Which of the following ultrasound beams has a characteristic that is most likely to cause temperature elevation in soft tissue?</p> <ul style="list-style-type: none"> <li>A. strongly focused</li> <li>B. medium focused</li> <li>C. unfocused</li> </ul>                           | <p><b>C.</b> An unfocused beam is most likely to cause temperature elevation in soft tissues. Temperature elevation with unfocused beams results from the broad area over which the beam spreads. With narrower, focused beams, the area insonated by the beam is smaller and therefore heats a smaller mass of tissue.</p> |
| <p>615. According to the AIUM, at what <i>in situ</i> tissue temperature is there danger to a fetus?</p> <ul style="list-style-type: none"> <li>A. 100° C</li> <li>B. 98.6° F</li> <li>C. 1° F over normal temperature</li> <li>D. 41° C</li> </ul>                                          | <p><b>D.</b> Elevation of fetal tissue in excess of 41° C is considered potentially harmful.</p>                                                                                                                                                                                                                            |

| Questions                                                                                                                                                                                                                                                                                                                                                                                                                                             | Answers                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>616. Research has indicated that cavitation ____.</p> <ul style="list-style-type: none"> <li>A. never occurs</li> <li>B. cannot occur with long pulses</li> <li>C. can be lethal to living things</li> <li>D. effects are purely theoretical</li> </ul>                                                                                                                                                                                            | <p><b>C.</b> Cavitation resulting from ultrasound exposure is lethal to the fruit fly. Cavitation has the potential for significant and harmful bioeffects under specific circumstances.</p>                                                                    |
| <p>617. Which of the following statements regarding cavitation is true?</p> <ul style="list-style-type: none"> <li>A. it has never been observed in any biologic media</li> <li>B. stable cavitation relates to oscillating bubbles while transient relates to bursting bubbles</li> <li>C. it is a nonlethal bioeffect produced in animal experiments</li> <li>D. waves with peak pressures less than 100 MPa can never induce cavitation</li> </ul> | <p><b>B.</b> This is the principal difference between the two forms of cavitation: stable cavitation means that the microscopic gas bubbles in the tissues are rhythmically swelling, whereas transient cavitation means the microscopic gas bubbles burst.</p> |
| <p>618. Which of the following is related to cavitation bioeffects?</p> <ul style="list-style-type: none"> <li>A. TIS</li> <li>B. MI</li> <li>C. cavitation index</li> <li>D. pulsatility index</li> </ul>                                                                                                                                                                                                                                            | <p><b>B.</b> The MI, or mechanical index, is related to cavitation bioeffects. Higher values of MI are associated with increased likelihood of cavitation.</p>                                                                                                  |
| <p>619. Which selection has the highest mechanical index?</p> <ul style="list-style-type: none"> <li>A. high frequency, high power</li> <li>B. high PRF, high intensity</li> <li>C. low frequency, high pressure</li> <li>D. high spatial pulse length, high PRF</li> </ul>                                                                                                                                                                           | <p><b>C.</b> The mechanical index is derived mathematically from the pressure in a sound beam and the sound's frequency. Mechanical index is highest with a high pressure sound beam of low frequency.</p>                                                      |
| <p>620. Which sound wave is least likely to create cavitation?</p> <ul style="list-style-type: none"> <li>A. 5 MHz, 2 MPa</li> <li>B. 2 MHz, 4 MPa</li> <li>C. 6 MHz, 2 MPa</li> <li>D. 2 MHz, 2 MPa</li> </ul>                                                                                                                                                                                                                                       | <p><b>C.</b> Low values of mechanical index indicate low likelihood of cavitation. Derived mathematically from a sound wave's frequency and pressure, mechanical index is lowest with high frequency and low pressure.</p>                                      |

| Questions                                                                                                                                                                                                                                                                                                                   | Answers                                                                                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>621. What is epidemiology the study of?</p> <ul style="list-style-type: none"> <li>A. large groups</li> <li>B. the prevalence of disease</li> <li>C. acoustic bioeffects on the fetus</li> <li>D. <i>in vitro</i> effects</li> </ul>                                                                                     | <p>B. Epidemiology is a division of medicine that is devoted to the study of the prevalence of diseases or pathology in a defined population.</p>                                                                                                   |
| <p>622. Epidemiologic studies of <i>in utero</i> exposure to ultrasound have included all of the following findings except ____.</p> <ul style="list-style-type: none"> <li>A. birth weight</li> <li>B. cancer</li> <li>C. structural abnormalities</li> <li>D. none of the above</li> </ul>                                | <p>D. Many epidemiologic studies on the effects of ultrasound have been reported. End points of birth weight, cancer, and structural abnormalities have all been studied. There is no correlation between ultrasound exposure and these events.</p> |
| <p>623. Which of the following epidemiologic studies is considered most likely to produce meaningful results?</p> <ul style="list-style-type: none"> <li>A. retrospective and prospective</li> <li>B. prospective and randomized</li> <li>C. retrospective and empirical</li> <li>D. prospective and mechanistic</li> </ul> | <p>B. A clinical trial that is both prospective and randomized is most likely to reach a valid and meaningful endpoint.</p>                                                                                                                         |
| <p>624. What is the highest SPTA intensity of an unfocused ultrasound wave where there have been no observed bioeffects?</p> <ul style="list-style-type: none"> <li>A. 1 mW/cm<sup>2</sup></li> <li>B. 100 mW/cm<sup>2</sup></li> <li>C. 1000 mW/cm<sup>2</sup></li> <li>D. 1 W/cm<sup>2</sup></li> </ul>                   | <p>B. There have been no independently confirmed significant bioeffects in mammalian tissue exposed to unfocused ultrasound with intensities below 100 mW/cm<sup>2</sup>.</p>                                                                       |
| <p>625. The upper limit for the SPTA intensity of a focused ultrasound wave where there have been no observed bioeffects is ____.</p> <ul style="list-style-type: none"> <li>A. 1 mW/cm<sup>2</sup></li> <li>B. 10 mW/cm<sup>2</sup></li> <li>C. 100 mW/cm<sup>2</sup></li> <li>D. 1 W/cm<sup>2</sup></li> </ul>            | <p>D. There have been no independently confirmed significant bioeffects in mammalian tissue exposed to focused ultrasound with intensities below 1 W/cm<sup>2</sup>.</p>                                                                            |



| Questions                                                                                                                                                                                                                                                                                                                                                                         | Answers                                                                                                                                                                                                                                                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 626. True or False? One reason focused ultrasound beams with low intensities are less likely to cause bioeffects is that a focused beam is less efficient in heating a large mass of tissue to a critical temperature.                                                                                                                                                            | <b>True.</b> With focused beams, only a small mass of tissue is heated, and the heat flows rapidly to cooler neighboring tissues. There is limited accumulation of heat energy and the temperatures tend to stay below critical levels.                               |
| 627. True or False? Focused sound beams are considered less likely to create bioeffects because the beams will strike fewer gas bubbles that could potentially cavitate.                                                                                                                                                                                                          | <b>True.</b> Small gas bubbles, or gaseous nuclei in tissues, serve as sites of cavitation. When a beam is focused, its diameter is smaller and is less likely to strike cavitation nuclei.                                                                           |
| 628. True or False? It is generally believed that the ultrasound bioeffects are minimal at intensity levels typical of those produced by diagnostic imaging equipment.                                                                                                                                                                                                            | <b>True.</b> Ultrasound is considered safe at levels typical of current diagnostic imaging equipment. The likelihood of significant, harmful bioeffects is extremely low.                                                                                             |
| 629. A comprehensive and scholarly review of bioeffects is performed by the American Institute of Ultrasound in Medicine for all of the following reasons <i>except</i> :<br>A. ultrasound is a versatile technique<br>B. ultrasound has proven widespread clinical utility<br>C. ultrasound is considered highly toxic<br>D. applications of ultrasound are growing considerably | <b>C.</b> The AIUM examines bioeffects research because diagnostic ultrasound is a clinically relevant, popular, and widely used imaging technique. Diagnostic ultrasound is not, however, considered highly toxic or likely to expose patients to substantial risks. |



# Index

## A

- absorption 84, 404
- accuracy
  - range 387
  - registration 387
- acoustic
  - impedance 88
  - parameters 12
  - propagation properties 11
  - variables 12
- acoustic waves 12
- acousto-optics 403
- actual velocity 310
- AIUM
  - conclusions regarding epidemiology 414
  - statement on clinical safety 415
  - statement on in vitro bioeffects 406
  - statement on prudent use 415
  - statement on safety in training and research 416
- ALARA 235, 417
- aliasing 316–322
  - avoiding artifact 319–322
  - color flow Doppler 347
  - vs flow reversal 348
- A-mode displays 159
- amplification 224, 235
- amplitude 27
  - A-mode display 159
  - peak-to-peak 28
  - relationship between amplitude and intensity 32
  - relationship between amplitude and power 29
  - squared 32
- analog numbers 242
- analog scan converter 243
- analog-to-digital (A-to-D) converter 247
- anatomy of sound beam 130
- anechoic image 356
- angles
  - types of 90
- annular array transducers 178–179
  - damaged PZT crystal 179
- apodization 193, 367
- array transducers 168
- artifacts 355–376
  - aliasing 319–322
  - axial resolution 370
  - causes of 355
  - clutter 374
  - comet tail 358
  - crosstalk 363
  - curved and oblique reflectors 371
  - Doppler 334
  - edge shadow 360
  - enhancement 361
  - focal enhancement 362
  - ghosting 334
  - lateral resolution 370

- lobe 366–367
- mirror image 363
- multipath 371
- practice Q&A 376–378
- reverberations 357
- ring down 358
- shadowing 359
- slice thickness 369
- spatial resolution 372–373
- speckle 374
- speed 364–365
- temporal resolution 372
- attenuation 80–87
  - absorption 84
  - half-value layer thickness 87
  - of ultrasound in media 86
  - reflection 81
  - scattering 82
- attenuation coefficient 84–85
  - in soft tissue 85
- audible sound 22
- autocorrelation 337
- autonomy 392
- average intensity
  - peak 71
  - pulse 71
- average velocity 325
- axial and lateral resolution 145–158
- axial resolution 145–150
  - and pulse length 147
  - artifact 370
  - evaluating 388
  - higher frequency pulses 148
  - LARRD 146
  - less ringing 148
  - practice Q&A 149

## B

- backing material 117
  - consequences of using 117
- backscatter 82

- bandwidth
  - Q-factor 119
  - transducer 118
- beam former 173, 216, 221
  - digital 221
  - switch 222
  - transmit focusing 174–176
- beam steering
  - electronic 169
  - linear phased arrays 172
  - linear sequential array 180
  - mechanical 167
- beneficence 392
- Bernoulli's Principle 293
- bidirectional Doppler 311
- binary digit 245
- binary numbers 245
- bioeffects 401–422
  - AIUM conclusions on epidemiology 414
  - AIUM statement on clinical safety 415
  - AIUM statement on in vitro 406
  - AIUM statement on prudent use 415
  - AIUM statement on safety in training and research 416
  - cavitation 410
  - clinical safety 415
  - electrical safety 417
  - empirical approach 407
  - in vitro 405
  - in vivo 405
  - mechanical index (MI) 412
  - mechanistic approach 407
  - overall safety considerations 417
  - practice Q&A 418–422
  - risk/benefit relationship 405–417
  - safety in training and research 416
  - stable cavitation 411
  - study techniques 407
  - Thermal Index (TI) 408
  - thermal mechanism 408
  - transient cavitation 411
- bioeffects mechanisms 408
- bioethics 391
- bistable images 239
- bit 245



blood, energy forms 289  
 B-mode displays 161  
 breathing and venous flow 300  
   practice Q&A 302  
 brightness  
   B-mode display 161  
 bruit 288  
 byte 245

## C

calibration  
   horizontal 387  
   vertical depth 387  
 calorimeter 404  
 cavitation 410  
   stable 411  
   transient 411  
 channel 223  
 characteristics  
   sound beam 130  
 clinical safety  
   AIUM statement 415  
   with ultrasound 415  
 clutter 334, 374  
 coded excitation 253  
 color Doppler gain 344  
 color flow Doppler 325  
 color maps  
   variance mode 328  
   velocity mode 326  
 comet tail artifact 358  
 compensation 226  
   TGC curve 228  
 compensation operation 389  
 complementary metric units 6  
 compounding imaging 254  
 compression 230–231, 266–267  
 consent  
   informed 393  
   revocation of 393  
 conservation of energy 97, 99  
 constructive interference 15

continuous wave  
   Doppler 312–313  
   parameters to describe 64  
   transducers 122  
 contrast agents 269–283  
 contrast harmonics 278–282  
   mechanical index (MI) 279  
   resonance 279  
 controls  
   display 240  
 conversion of units 5  
 converter  
   analog scan 243  
   analog-to-digital (A-to-D) 247  
   digital scan 241, 243  
   digital-to-analog (D-to-A) 248  
   scan 241  
 convex, curved, or curvilinear array transducer  
   184–185  
 correlation function 337  
 cosine 309  
 crosstalk 335  
 crosstalk artifact 363  
 Curie point 120  
 Curie temperature 120  
 curved reflector artifact 371  
 cysts, checking dimensions 389

## D

damping material 117  
 dead zone  
   performance measurements 386  
 decibel notation 77  
 decibels 77–79  
   negative 78  
   notation 77  
   positive 77  
   practice Q&A 79  
 decimal numbers 245  
 dedicated continuous wave transducer 313  
 demodulation 232, 304  
 density 12  
   line 206  
   pixel 244

- ul>
- depth calibration 387
- depth of view 54
- describing sound waves 19–46
- destructive interference 15
- diffraction pattern 142
- diffuse reflection 82
- digital beam former 221
- digital displays 373
- digital numbers 242
- digital scan converter 241, 243
  - advantages 243
- digital-to-analog (D-to-A) converter 248
- digitizing an image 243
- dignity, patient 394
- directly proportional 2
- directly related, or directly proportional 2
- disinfection 120
- display modes 159–163
  - A-mode 159
  - B-mode 161
  - M-mode 162
  - practice Q&A 163
- displays
  - bistable 239
  - controls 240
  - digital 373
  - gray scale 239
  - image storage 239–264
  - practice Q&A 261
  - pulsed echo instrumentation 216
- distance 12
- divergence 139–141
- Doppler 303–340
  - aliasing 316–322
  - autocorrelation 337
  - bidirectional 311
  - clutter 334, 374
  - color 325
  - color maps 326
  - color power mode 333
  - continuous wave 312–313
  - crosstalk 335, 363
  - duplex imaging 313
  - equation 306
  - Fast Fourier Transform 336
  - frequency 303
  - ghosting 334
  - gray scale of spectrum 324
  - lookup table 326
  - modality roles 337
  - packet 332
  - phantoms 383
  - practice Q&A 338–339
  - pulsed wave 314
  - pulsed wave transducer 315
  - rectangular image 331
  - sector image 330
  - spectral analysis 335
  - variance mode map 328
  - velocity 305
  - velocity mode map 326
- Doppler shift 303–308
  - blood flow vs. sound beam direction 309
  - negative 305
  - positive 304
  - relationship with transmitted frequency 308
  - relationship with velocity of blood 306
- dosimetry 405
- duplex imaging 313
- duration
  - pulse 49–50
- duty factor 60–61, 74
- dynamic aperture 194
- dynamic frequency tuning 234
- dynamic range 265–268
  - compression 266–267
  - low 268
  - number of choices 268
  - of ultrasound system components 266
  - wide 268
- dynamic receive focusing 177, 185
- ## E
- echo 88
  - edge enhancement 255
  - edge shadow artifact 360
  - elastography 258
  - electrical safety 417
  - electronic focusing 155, 167, 181

electronic steering 169  
 electronic transmit focusing 181  
 elevational 369  
 elevational resolution 369, 384  
   See also *slice resolution*.  
 empirical approach 407  
 energy  
   frictional loss 290  
   gravitational 290  
   inertial loss 291  
   kinetic 289  
   potential 289  
   pressure 289  
   viscous loss 290  
 energy forms associated with blood 289  
 energy gradient 289  
 energy loss 290  
 energy loss in blood flow 290  
 energy mode, Doppler 333  
 engineering notation 6  
 enhancement artifact 361  
 enhancement, focal 362  
 epidemiology 413  
   AIUM statement 414  
   prospective studies 413  
   randomized studies 414  
 ergonomics 394  
 exam  
   interpretation 394  
 expiration 301  
 exponents 6  
 external focusing 155

## F

far field or far zone 131  
 Fast Fourier Transform (FFT) 336  
 fill-in interpolation 257  
 fixed focusing 167  
 flow 285, 286–291, 348  
   and sound beam 309  
   energy gradient 289  
   laminar 287, 336  
   parabolic 287  
   plug 287

pulsatile 286  
 steady 286  
 turbulent 288, 336  
   venous, effect of respiration on 300  
 flow reversal vs aliasing 348  
 focal banding 362  
 focal depth 131, 135–138  
 focal enhancement 362  
 focal length 131, 135–138  
 focal point 131  
 focal zone 131, 362  
   evaluating 388  
 focusing 154–156  
   dynamic receive 177, 185  
   electronic 167, 181, 185, 187  
   external 155  
   fixed techniques 154  
   internal 155  
   linear phased array 174–176  
   mechanical transducers 167  
   multi-focusing 167  
   phased arrays 155, 174–176  
   sound beam 131  
 force, radiation 403  
 frame rate 198, 201  
   relationship with time 199  
   settings that determine 199  
 Fraunhofer zone 131  
 frequency  
   audible sound 22  
   describing sound waves 21  
   dynamic tuning 234  
   fundamental 269  
   harmonic 269  
   infrasound 22  
   pulses 148  
   PZT crystals 125  
   relationship between frequency and period 22  
   spectrum of sound 22  
   transducer 122  
 Fresnel zone 131  
 frictional energy loss 290  
 functions, receiver 234  
 fundamental frequency 269  
 fundamental image 270



## G

- gain
  - color Doppler 344
  - receiver 235
- gaseous nuclei 410
- gel, impedance 116
- ghosting artifact 334
- go-return time 107
  - 13-microsecond rule 108
- graphs 1
- grating lobes 192, 367
  - subdicing 367
- gravitational energy 290
- gray scale
  - displays 239
  - Doppler spectrum 324
  - edge enhancement 255
  - evaluating with a phantom 382
  - fill-in interpolation 257
  - mapping 230
  - scan converter 241

## H

- half-value layer thickness 87
- harmonic frequency 269
- harmonic imaging 269–283, 375
  - linear behavior 271
  - nonlinear behavior 271
- harmonics
  - contrast 278–282
  - power modulation 277
  - pulse inversion 275
  - tissue 272–283
- hematocrit 290
- hemodynamics 285–302
  - blood energy forms 289
  - energy gradient 289
  - energy loss in blood flow 290
  - flow 285, 286–291
  - laminar flow 287
  - parabolic flow 287
  - plug flow 287
  - practice Q&A 297, 299, 302

- pressure-flow relationship 294
- pulsatile flow 286
- steady flow 286
- turbulent flow 288
- velocity 285
- venous 295
- viscosity 290
- hertz (Hz) 24
- heterogeneous image 356
- homogeneous image 356
- horizontal axis (x-axis) 1
- horizontal calibration 387
- Huygens' Principle 142
- Huygens' wavelets 142
- hydrophone 401–402
- hydrostatic pressure 296–299
- hyperechoic image 356
- hypoechoic image 356

## I

- image
  - anechoic 356
  - characteristics 356
  - fundamental 270
  - harmonic 270
  - hyperechoic 356
  - hypoechoic 356
  - isoechoic 356
  - rectangular 331
  - sector 330
  - storage 239–264
- image information, translating 247
- image shape
  - curved array transducer 185
  - linear phased array 169
  - mechanical transducer 167
  - vector arrays 187
- imaging
  - characteristics 356
  - data 247–259
  - depth 54, 200
  - digitizing 243
  - duplex 313
  - harmonic 269–283, 375

- magnification 250
  - multi-focus 202
  - postprocessing 248
  - practice Q&A 261
  - preprocessing 247
  - read magnification 250
  - recording and archiving techniques 260
  - scan converter 241
  - shallow vs. deeper 61
  - single focus 202
  - six assumptions of a system 356
  - write magnification 251
  - impedance 88
    - matching layer 116
    - of gel 116
    - of PZT 116, 117
    - of the damping element 117
  - importance of wavelength 35
  - in vitro 405
    - AIUM statement 406
  - in vivo 405
  - incidence 90–103
    - angle of 100
    - normal 91
    - oblique 91, 98
  - incident intensity 92
  - inertial cavitation
    - See *transient cavitation*.
  - inertial energy loss 291
  - information, translating image data 247
  - informed consent 393
    - revoking 393
  - infrasound 22
  - in-phase waves 14
  - inspiration 300
  - intensity 31, 69–74
    - “Ten Commandments” of 74
    - average 71
    - incident 92
    - intensity reflection coefficient (IRC) 93
    - intensity transmission coefficient (ITC) 93, 97
    - keywords for reporting pulsed waves 69
    - measuring 71, 73
    - peak 71
    - pulse average 71
    - pulsing characteristics 71
    - reflected 92
    - relationship between intensity and amplitude 32
    - relationship between intensity and power 32
    - spatial average 70
    - spatial considerations 70
    - spatial peak 70
    - temporal considerations 71
    - temporal measurements 72
    - temporal peak 71
    - transmitted 92
  - intensity reflection coefficient (IRC) 93
  - intensity transmission coefficient (ITC) 93, 97
  - interaction of patient and sonographer 394
  - interaction, of sound and media 75–106
  - interference 14
    - constructive 15
    - destructive 15
    - waves with different frequencies 15
  - internal focusing 155
  - interpolation, fill-in 257
  - inversely proportional 3
  - inversely related 3
  - isoechoic image 356
- ## J
- justice 392
- ## K
- kinetic energy 289
- ## L
- laminar flow 287, 336
  - LARRD (mnemonic) 146
  - LATA (mnemonic) 151
  - lateral resolution 151–153, 203, 235, 388
    - artifact 370
  - line density 206
  - linear behavior 271

- linear phased array
  - image shape 169
  - transducer 169–177
- linear sequential array
  - beam steering 180
- linear sequential array transducer 180–183
- liquid crystals 404
- listening time 55
- lobes
  - apodization 367
  - artifacts 366–367
  - grating 192, 367
  - side 192, 367
- logarithm 76
- logarithmic scale 76
  - examples 76
- longitudinal resolution 235
  - See also *axial resolution*.
- longitudinal wave 11, 13
- low dynamic range 268

## M

- magneto-optical storage 259
- magnification 250
  - read 250
  - write 251
- maleficence 392
- mapping, gray scale image 230
- master synchronizer 216
- matching layer impedance 116
- measured velocity 310
- measurement
  - intensity 71, 73
  - temporal intensity 72
- mechanical index (MI) 279, 412
- mechanical steering
  - annular phased array transducers 178
  - of beams 167
- mechanical transducer 167
  - focusing 167
  - image shape 167
- mechanism
  - cavitation 410
  - thermal 408

- mechanisms, bioeffects 408
- mechanistic approach 407
- media
  - interaction with sound 75–106
  - ultrasound system 216
- medium
  - density 38, 39
  - determining sound wave parameters 20
  - stiffness 38, 39
- metric units, complementary 6
- microbubbles 278–282
- microprobe 401–402
- mirror image artifact 363
- M-mode displays 162
- modality roles, Doppler 337
- motion mode (M-mode) 162
- multi-focus imaging 202
- multi-focusing, annular phased arrays 178
- multipath artifact 371
- multiple focus zones 203
- murmur 288

## N

- near field or near zone 131
- near zone length 131, 135–138
- noise 219, 374
  - signal-to-noise ratio 219
- nonlinear behavior 271, 272
- nonmaleficence 392
- normal cavitation
  - See *transient cavitation*.
- normal incidence 91
  - color flow Doppler 342
- number of choices 268
- number of pulses per image 201
- numbers
  - analog 242
  - binary 245
  - decimal 245
  - digital 242
- numerical values and corresponding units 5
- Nyquist frequency or limit 316



## O

- objective standard 381
- oblique incidence 91, 98
  - conservation of energy 99
  - transmission 100
- oblique reflector artifact 371
- Ohm's Law 294
- OSHA, universal precautions 396
- out-of-phase waves 14
- output
  - transducer 217
- output power 218, 235
  - vs. receiver gain 236

## P

- packet, Doppler 332
- PACS 259
- parabolic flow 287
- parameters
  - "bigness" 27
  - acoustic 12
  - amplitude 27
  - intensity 31
  - power 29
  - propagation speed 36
  - to describe pulsed waves 64
  - to describe sound waves 19–46
    - frequency 21
    - period 20
  - wavelength 33
- patient
  - and sonographer interaction 394
  - dignity 394
- patient communication 391–400
- peak intensity 71
- peak velocity 325
- peak-to-peak amplitude 28
- performance measurements
  - dead zone 386
  - registration accuracy 387
  - sensitivity 385
- period
  - describing sound waves 20
  - relationship between period and frequency 22
- persistence 256
- phantoms 382–384
  - Doppler 383
  - slice thickness 384
  - tissue equivalent 382
- phase delays 172
- phased array
  - annular 178–179
  - focusing 155
  - focusing sound beam 174–176
  - linear 169–177
- phasing 169
- picture archiving and communications system (PACS) 259
- picture element 244
- piezoelectric effect 113
  - reverse 113
- piezoelectric materials 113
  - Curie temperature or Curie point 120
  - speed of sound in 124
- pixel 244
- pixel density 244, 373
- plug flow 287
- population studies 413
- postprocessing 248, 249
- power 29
  - output 218
  - relationship between power and amplitude 29
  - relationship between power and intensity 32
- power mode, Doppler 333
- power modulation harmonics 277
- powers of ten 6
- practice Q&A
  - artifacts 376–378
  - attenuation, half-value layer, and impedance 89
  - axial resolution 149
  - basics 7
  - bioeffects 418–422
  - breathing and venous flow 302
  - decibels 79
  - describing sound waves 41–46
  - display modes 163
  - displays and image storage 261
  - Doppler 338–339
  - hydrostatic pressure 297, 299

- lateral resolution 157
- period and frequency 25
- pulsed echo instrumentation 236–237
- pulsed waves 65–68
- range 111
- real-time imaging 210–214
- reflection 96
- reflection, transmission, and refraction 104
- relationships 4
- sound 16–18
- sound beams and lateral resolution 158
- transducers 126–128
- two-dimensional imaging 195
- preamplification 225
- preprocessing 247, 249
- pressure 12
  - hydrostatic 296–299
  - relationship to flow (hemodynamics) 294
- pressure energy 289
- pressure-flow relationships 294
- propagation speed 36, 364–365
- proportional 2
  - directly 2
  - inversely 3
- prospective studies 413
- prudent use
  - AIUM statement 415
- pulsatile flow 286
- pulse
  - duration 49–50, 54
  - duty factor 60–61
  - higher frequency 148
  - length 51–52
  - less ringing 148
  - number per image 201
  - ultrasound 48
- pulse average intensity 71
- pulse inversion harmonics 275
- pulse repetition frequency (PRF) 56–58, 110, 220
- pulse repetition period (PRP) 53–55, 109, 220
  - components 54
- pulsed echo instrumentation 215–237
  - practice Q&A 236–237

- pulsed wave Doppler 314
  - aliasing 316–322
- pulsed wave Doppler transducers 315
- pulsed wave transducer
  - frequency and speed 124
- pulsed waves 47–68
  - key words for reporting 69
  - parameters to describe 64
  - practice Q&A 65–68
- pulser 216, 217
- pulsing characteristics 71
- PZT crystal 117
  - damaged annular array transducer 179
  - damaged curved array transducer 185
  - damaged in a mechanical transducer 167
  - damaged linear sequential array 182

## Q

- Q-factor 119
- quality assurance 379–389
  - dead zone performance measurements 386
  - goals 380
  - registration accuracy performance
    - measurements 387
  - requirements 380
  - sensitivity performance measurements 385
- quality factor 119

## R

- radiation
  - force 403
- randomized studies 414
- range 107–112
- range accuracy 387
- range ambiguity 312
- range resolution 314
- ratio, signal-to-noise 219
- Rayleigh scattering 83
- read magnification 250
- real-time imaging 197–214
  - practice Q&A 210–214

- receiver 216, 223
  - amplification 224
  - compensation 226
  - compression 230–231
  - demodulation 232
  - functions 234
  - order of operations 223
  - reject 233
- receiver gain 235
  - vs. output power 236
- reciprocal relationship 3
- recording ultrasound images 260
- rectangular image 331
- rectification 232
- reflected intensity 92
- reflection 81, 88
  - angle of 100
  - diffuse 82
  - specular 81
  - with normal incidence 95
  - with oblique incidence 98, 99
- refraction
  - sine 102
- region of interest (ROI) 250, 251
- registration accuracy 387
- reject 233
- related, or proportional 2
- relationships
  - between actual velocity and measured velocity 310
  - between amplitude and power 29
  - between frame rate and time 199
  - between intensity and amplitude 32
  - between intensity and power 32
  - between intensity, power, and amplitude 32
  - between wavelength and frequency 34
  - directly proportional 2
  - frequency and period 22
  - practice Q&A 4
  - pressure to flow 294
  - proportional 2
  - PRP and depth of view 54
  - pulse repetition period (PRP) and pulse repetition frequency (PRF) 58
  - reciprocal 3
  - sound beam directions and flow direction 309
  - stiffness and density of a medium on sound waves 38, 39
  - temporal resolution and image quality 208
  - transmitted frequency and Doppler shift 308
  - unrelated 2
  - velocity of blood and Doppler shift 306
- research
  - in vitro 405
  - in vivo 405
- resolution 145–158, 369
  - axial 145–150, 370, 388
    - higher frequency pulses 148
    - LARRD 146
    - less ringing 148
  - elevational 384
  - image quality 208
  - lateral 151–153, 203, 235, 370, 388
  - longitudinal 235
  - multi-focus beam 203
  - slice thickness 188–190
  - spatial 372–373
  - temporal 372
  - wide vs. narrow sector 204
- resonance 279
- respiration
  - effect on venous flow 300
  - expiration 301
  - inspiration 300
- reverberation 357
- reverse piezoelectric effect 113
- review questions
  - artifacts 376–378
  - attenuation, half-value layer, and impedance 89
  - axial resolution 149
  - basics 7
  - bioeffects 418–422
  - breathing and venous flow 302
  - decibels 79
  - describing sound waves 41–46
  - display modes 163
  - displays and image storage 261
  - Doppler 338–339
  - hydrostatic pressure 297, 299
  - period and frequency 25



- pulsed echo instrumentation 236–237
- pulsed waves 65–68
- range 111
- real-time imaging 210–214
- reflection 96
- reflection, transmission, and refraction 104
- relationships 4
- sound 16–18
- sound beams 143–144
- sound beams and lateral resolution 157, 158
- transducers 126–128
- two-dimensional imaging 195
- revoking informed consent 393
- Richter Scale, example of logarithmic scale 76
- ring down artifact 358
- ringing 148
- Rules of Thumb for stiffness, density, and speed 39

## S

- safety
  - electrical 417
  - in training and research 416
  - overall considerations 417
  - use of ultrasound 415
- SATA intensity 74
- scale
  - increasing Doppler 354
- scan converter 241
  - analog 243
  - digital 241, 243
- scattering 82
  - Rayleigh 83
- Schlieren shadowing system 403
- Scientific notation 6
- sector image 330
- sensitivity 385
- shadowing
  - edge 360
- shadowing artifact 359
- shape, sound beam 130
- side lobes 192, 367
- signal-to-noise ratio 219
- sine 102

- single element transducers 192
- single focus imaging 202
- slice thickness
  - artifact 369
  - phantom 384
  - resolution 188–190
- sloped-shaped delays 183
- smoothing 232
- Snell's Law 102
- soft tissue
  - attenuation coefficient 85
- sonographer
  - interaction with patient 394
  - interpretation of exam 394
- sonography 35
- sound
  - audible 22
  - conservation of energy 97
  - determining speed in a medium 38
  - infrasound frequency 22
  - interaction with media 75–106
  - practice Q&A 16–18
  - pulsed 47–68
  - speed in PZT materials 124
- sound beams 129–144
  - characteristics 130
  - divergence 139–141
  - far zone 131
  - focal length 131
  - focal point 131
  - focal zone 131
  - focusing phased array systems 174–176
  - near zone 131
  - practice Q&A 143–144
  - shape 130
- sound waves 11
  - acoustic propagation properties 11
  - constructive interference 15
  - describing 19–46
  - describing amplitude 27
  - describing intensity 31
  - describing power 29
  - describing wavelength 33
  - destructive interference 15
  - frequency 21

- identifying 12
- in-phase 14
- interference 14
- interference with different frequencies 15
- longitudinal 13
- out-of-phase 14
- period 20
- practice Q&A 41–46
- transverse 13
- source of a sound wave 20
- spatial average intensity 70
- spatial compounding 254, 256
- spatial considerations 74
- spatial peak intensity 70
- spatial pulse length 51–52, 146
- spatial resolution 372–373
- speckle 374
- spectral analysis 335
- spectral window 336
- specular reflection 81
- speed 36
  - characteristics of a medium that determine sound speed 38
  - of sound in biologic tissues 37
  - of sound in soft tissue 37
  - relationship of stiffness 38, 39
  - rule of thumb for remembering density and stiffness 39
  - vs. velocity 305
- speed error artifact 364–365
- spherical waves 142
- SPTA intensity 74
- stable cavitation 411
- standards for QA 381
- static scanning 197
- steady flow 286
- steering
  - electronic 169
  - mechanical 167
  - vector array 186
- stenosis 292
- sterilization 120
- stiffness and sound speed 38

- storage
  - magneto-optical 259
  - ultrasound system 216
- storing images 239–264
- study techniques
  - empirical approach 407
  - mechanistic approach 407
- subdicing 367
- subjective standard 381
- switch
  - beam former 222
- synchronizer, master 216

## T

- temporal averaging 256
- temporal considerations 74
- temporal intensity
  - considerations 71
  - values 72
- temporal peak intensity 71
- temporal resolution 198, 372
  - image quality 208
  - imaging depth 200
  - line density 206
  - narrow sector 204
  - number of pulses per image 201
  - wide sector 204
- “Ten Commandments” of intensity 74
- TGC curve 228
- Thermal Index (TI) 408
- thermal mechanism 408
- thermocouple 404
- 13-microsecond rule 108
- thrill 288
- time gain compensation (TGC) curve 228
- time-of-flight 107
- tissue
  - speckle 374
  - speed of sound in 37
  - speed of sound in soft tissue 37
  - wavelength in soft tissue 34
- tissue equivalent phantoms 382
  - checking dimensions of cysts and texture 389

tissue harmonics 272–283  
 nonlinear behavior 272  
 training and research  
     safety 416  
 transducer arrays 168  
 transducers 113–128, 216  
     annular phased array 178–179  
     array 168  
     bandwidth 118  
     basic construction 114  
     components 115  
     continuous wave 122, 313  
     convex, curved, or curvilinear array 184–185  
     disinfecting 120  
     electrical safety 417  
     frequencies 122  
     imaging 119  
     less ringing 148  
     linear phased array 169–177  
     linear sequential array 180–183  
     mechanical 167  
     non-imaging 119  
     output 217  
     output and noise 219  
     practice Q&A 126–128  
     pulsed wave  
         Doppler 315  
     single-element 192  
     vector array 186–187  
 transient cavitation 411  
 translating image data 247  
 transmission 88  
     conservation of energy 97  
     with oblique incidence 98, 100  
 transmit focusing linear phased array 174–176  
 transmit time 54  
 transmitted intensity 92  
 transverse wave 13  
 tuning, dynamic frequency 234  
 turbulent flow 288, 336  
     murmur or bruit 288  
 two-dimensional imaging 165–196  
     annular phased arrays 178–179  
     convex, curved, or curvilinear arrays 184–185  
     linear phased arrays 169–177

linear sequential arrays 180–183  
 mechanical transducer 167  
 practice Q&A 195  
 vector arrays 186–187

## U

ultrasonic sound 22  
 ultrasound  
     basic assumptions of system design 356  
     basic transducer construction 114  
     calculating blood velocity 307  
     clinical safety and prudent use 415  
     dynamic range of system components 266  
     electrical safety 417  
     image characteristics 356  
     pulses 48  
     range 107–112  
     recording and storing images 260  
 ultrasound systems  
     components 216  
 ultrasound wave frequency 22  
 uniformity 389  
 units  
     complementary metric 6  
     conversion of 5  
     defined 5  
 unrelated 2

## V

variance mode maps 328  
 vector array transducer 186–187  
 velocity 285, 305  
     actual 310  
     average 325  
     cosine of the angle 309  
     measured 310  
     peak 325  
     vs. speed 305  
 velocity mode map 326  
 venous flow, effect of respiration 300  
 venous hemodynamics 295  
 vertical axis (y-axis) 1  
 vertical depth calibration 387



viscosity 290  
viscous energy loss 290  
volume flow rate 285  
V-shaped wave 142

## W

wall filter  
    color flow Doppler 351  
    spectral Doppler 352  
    vs increasing scale 354  
wave  
    constructive interference 15  
    destructive interference 15  
    different frequencies 15  
    in-phase 14  
    interference 14  
    longitudinal 13  
    out-of-phase 14  
    pulsed, key words for reporting 69  
    sound 11  
    spherical 142  
    transverse 13  
    V-shaped 142  
wavelength 33  
    importance in diagnostic sonography 35  
    in soft tissue 34  
    relationship between wavelength and  
        frequency 34  
wide dynamic range 268  
word 245  
write magnification 251

## X

x-axis 1

## Y

y-axis 1

## Z

zone  
    focal 131  
    Fraunhofer 131  
    Fresnel 131  
    near 131  
zoom 250

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